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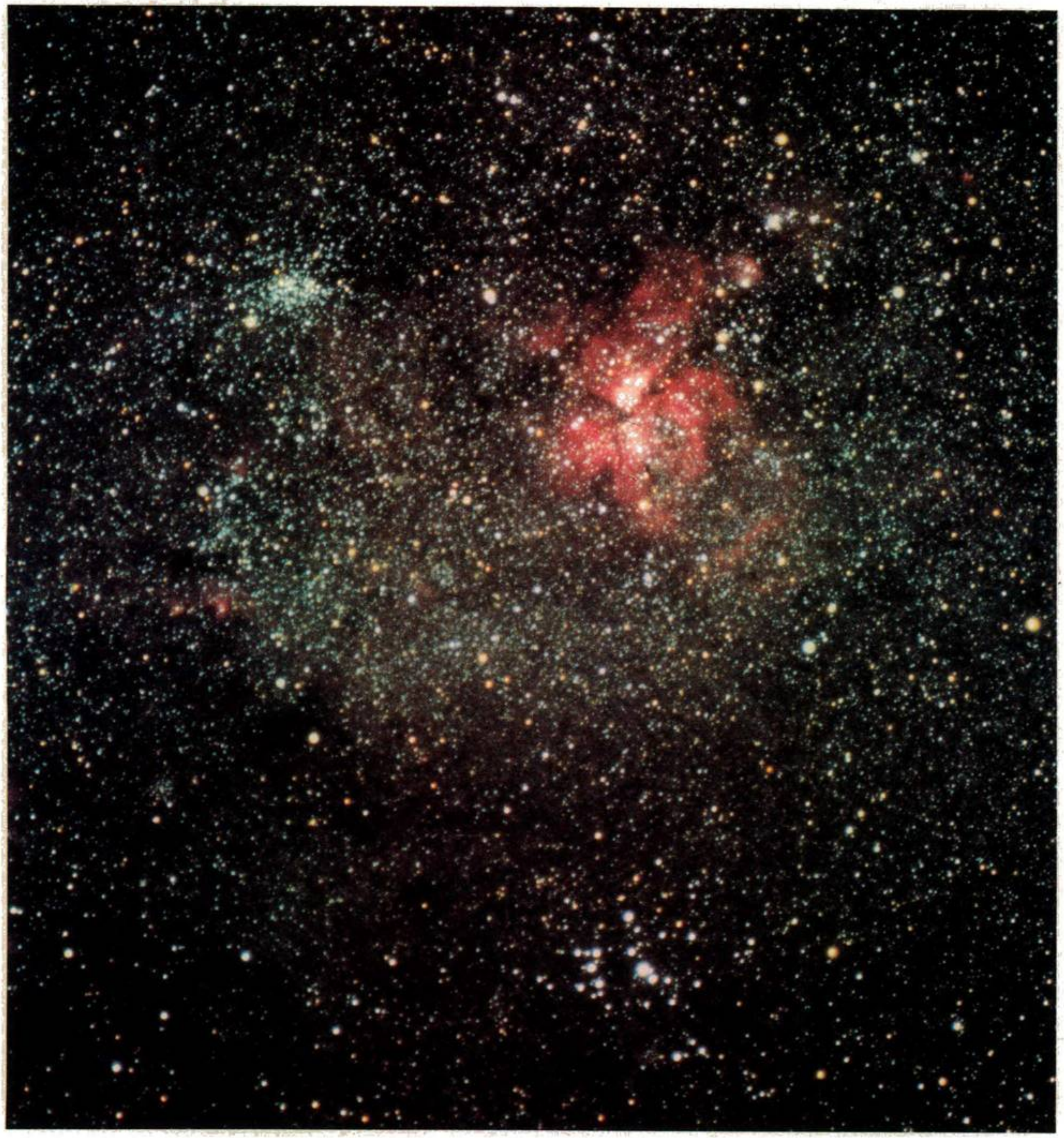

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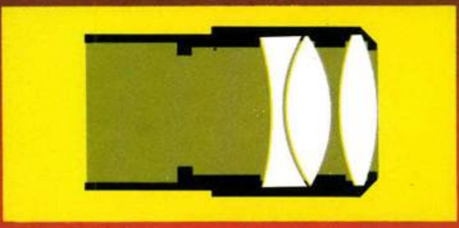

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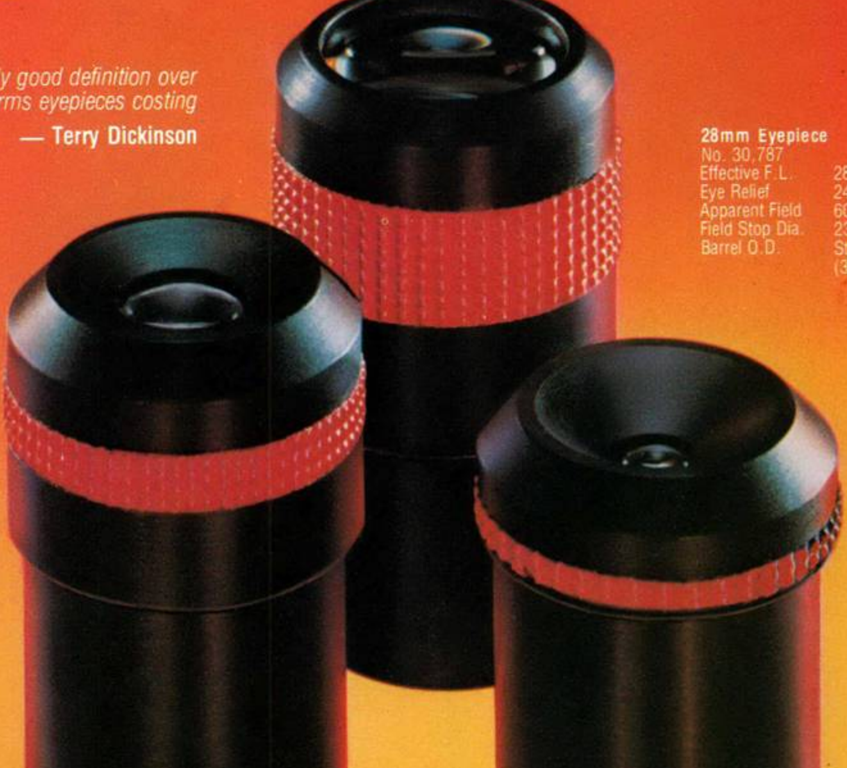

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Richard Berry

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COVER

The rich region around the Eta Carinae nebula (NGC-3372) graces this month's cover with thousands of stars and two prominent star clusters: NGC-3532 at upper left, and IC-2602, the loose collection of stars at the bottom. This month ASTRONOMY takes you on a trip around our Milky Way in Gazer's Gazette, and explores an astronomical controversy that in questioning the redshift-distance relationship gnaws at the very roots of modern cosmology. Then in Stellar Frontiers, you'll read about another profound cosmological problem that rests on the simple fact that the sky is dark at night! Our cover photo is a 60 minute exposure on Ektachrome 200 taken with a 105mm f/2.5 lens. Photograph by Ronald Royer.

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THE REDSHIFT PROBLEM

by
Barry Parker

Take a careful look at the photograph on this page. Do you see the luminous bridge between the galaxy and the round object directly below it? Does the luminous bridge actually connect the two objects? Look very carefully. This photograph, along with several others, is currently causing a raging controversy in the world of astronomy. Why? Because the galaxy and the quasar have different redshifts.

If the luminous bridge actually connects them, how could they have different redshifts? Remember...the universe is expanding. We've known for years that objects with the same redshift lie at the same distance from us — assuming, of course, that they obtained their recessional velocity in the big bang explosion. The distant galaxies and clusters of galaxies are moving away from us; the farther they are away, the faster they are traveling. This relationship between their distance and speed is known as *Hubble's law*. As far as we know, all galaxies and quasars satisfy it.

If the galaxy and quasar in the photograph have different redshifts, they must lie an enormous distance apart. They can't possibly be connected as they appear to be — unless, of course, something is drastically wrong. Is it possible perhaps that the Doppler shift interpretation of the redshifts is incorrect for one of these objects?

You are probably already familiar with the Doppler shift in relation to trains. Let's suppose you see a train coming toward you. The engineer, in turn, sees you and toots his whistle. As it gets closer, you hear the pitch of the whistle suddenly increase; then as the train passes, the pitch of the sound drops. Pitch and frequency are the same thing, so what you observe is that the frequency of the sound wave increases as the source approaches and decreases as it recedes. This is the *Doppler effect*.

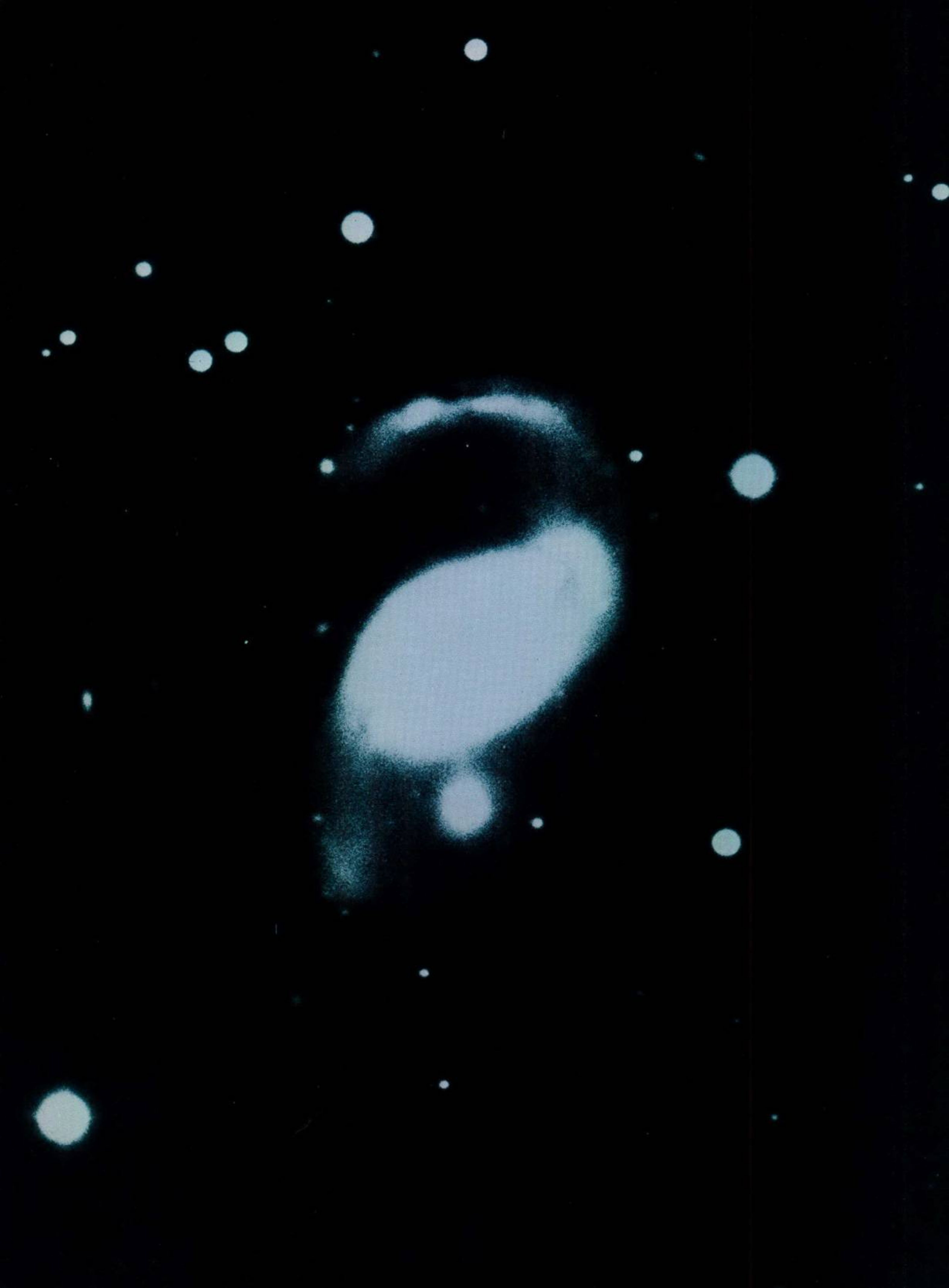
Light is also a wave, and it therefore also has a frequency. If a star recedes from us, the frequency of its light decreases; we see this decrease as a shift of its spectral lines toward the red end (or "lower pitch" part) of the spectrum. This is the *redshift* we referred to earlier.

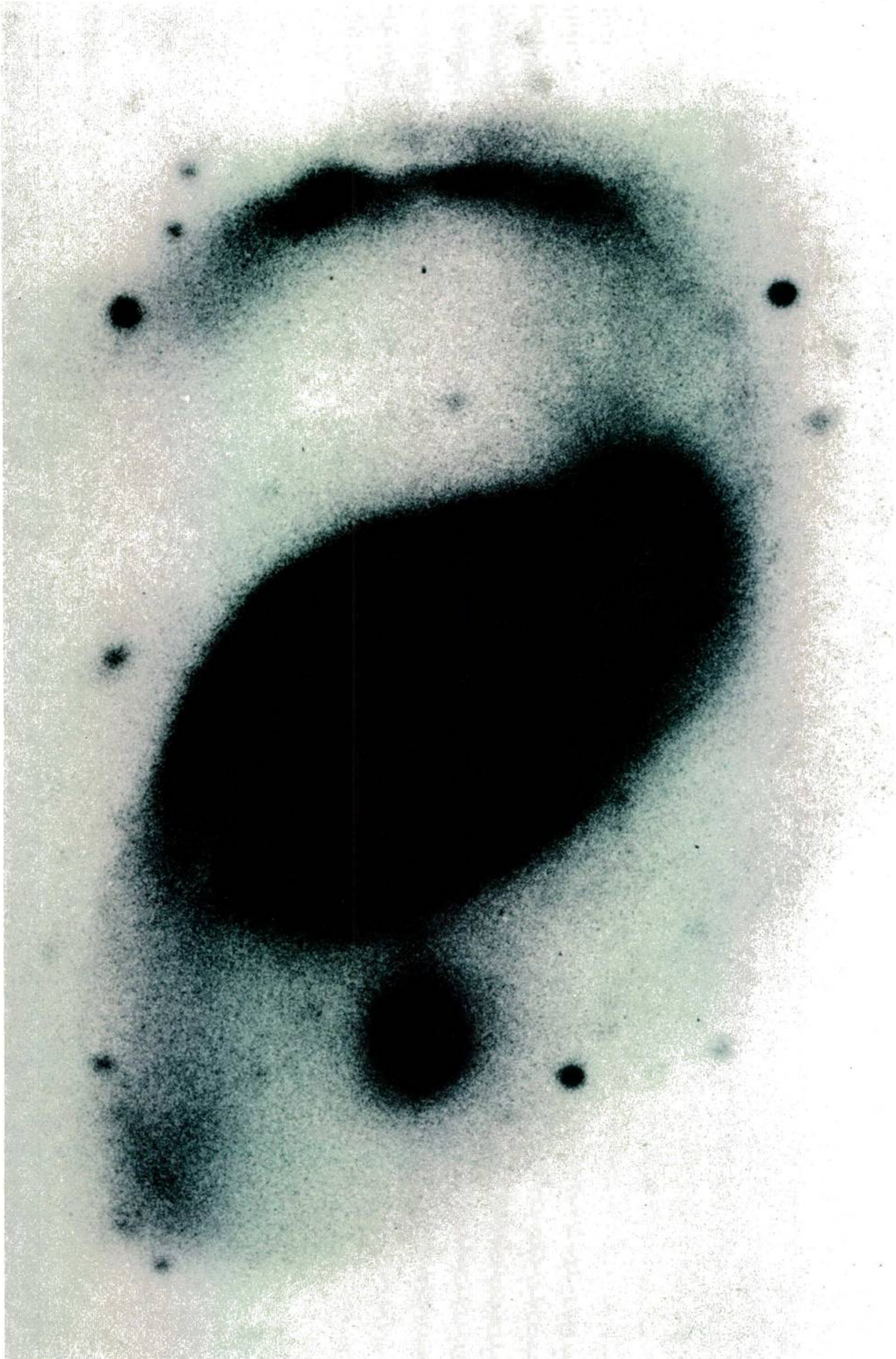
Now, if someone handed you the spectrum of a star and you noticed that its lines were shifted toward the red, you'd know that the star was traveling away from you. Similarly, when a star approaches you, its lines shift toward the blue end of the spectrum. What we are actually doing in each of these cases is interpreting the shift as a Doppler shift.

The Doppler interpretation is certainly valid for nearby objects: Light from the receding limb of the sun shows a redshift. The receding stars in nearby double star systems also show redshifts. Similarly, the approaching stars show blueshifts. In each of these cases we are certain the shift is due to the motion of the star relative to us. Why, then, shouldn't the Doppler interpretation also apply to the galaxy and quasar in our photograph?

Let's take a closer look at them. They were first brought to our attention in 1970 by D. W. Weedman of McDonald Observatory. Because they were so close together, Weedman was sure they were connected — but he didn't have proof. He did, however, suggest they might have different redshifts. In 1971, astronomer Halton Arp of Hale Observatories decided to investigate. First he obtained their spectra and verified that the redshifts were, indeed, different. They indicated that the galaxy was traveling at 0.6 percent the

This 3 hour 40 minute exposure with the Hale 200 inch telescope shows the galaxy NGC-4319 and the quasar Markarian 205. The redshift of the galaxy is 1,800km per second, while that of the quasar is 21,000km per second. Yet — astonishingly — they appear to be connected by a straight sided luminous bridge. A closeup on this region is on page 8. Photograph copyright © 1971 by California Institute of Technology and Carnegie Institution of Washington.





speed of light away from us, but the quasar was receding at seven percent the speed of light.

Arp took a four hour exposure of the pair using the 200 inch (5m) Palomar telescope. Special fine grained films were used. The results were amazing: Between the two objects was a clearly visible luminous bridge! Arp studied the pair at different wavelengths. He particularly wanted to photograph it in H-alpha light. If the bridge were hydrogen emission, it would then show up strongly. When he finally did obtain an H-alpha photograph, the bridge was there.

Now, back to the question: Does the luminous bridge actually connect the galaxy and the quasar? Arp is convinced it does. Other astronomers do not agree with Arp, however. Roger Lynds and A. G. Millikan of Kitt Peak National Observatory also took a long exposure of the pair using the Kitt Peak 78 inch (2m) telescope. Though they verified that there was a bridge of sorts, they didn't believe it actually connected the two objects. Further, they were unable to find the bridge in H-alpha light. They suggested that the bridge is simply a spurious effect arising from the chance superimposition of the two objects. If this is true, there should be a gradual change in the width of the bridge across the gap. In Arp's photographs this isn't so — the bridge is narrow and straightsided.

In 1974, Merle F. Walker, C. D. Pike and J. D. McGee of Lick Observatory decided to look, in detail, at the bridge near the connection. Using isophotal photographs (maps of equal brightness, much like the equal pressure lines you see on a weather map), they looked for some indication of a disturbance in the direction of the quasar that might indicate a relationship between the two objects. Though they found none, they had looked only at the outer (that is, the faintest) isophotes.

Arp, along with Neil Pratt of the Royal Observatory (Edinburgh, Scotland) and Jack Sulentic of the State University of New York, then made isophotal curves from their own photographs. They found that the inner (brighter) isophotals were indeed disturbed, though not exactly in the direction of the quasar. Almost directly across the galaxy they noticed another disturbance where the isophotal lines were sharply extended.

Arp believes his results support a startling hypothesis: that the quasar was ejected from the galaxy some time in the past. He noticed that by drawing lines through the two extensions of the galaxy, one of the lines passes about 30 degrees from the direction of the quasar. Extending a line from the other disturbance, he found there was a radio source 30 degrees from that line too! A coincidence? Arp doesn't think so. In fact, he thinks the galaxy ejected both quasars! The disturbed regions indicate where they were thrown out, and their ejection speed accounts for the high redshift.

What Is A Quasar?

No one really knows what quasars are. Now that they've been the subject of intensive research for 16 years — ever since astronomers realized just how peculiar they are — there are a lot of theories about them. But even though no one knows exactly what they are, astronomers have very definite criteria for quasars.

A quasar is a radio source with a small angular diameter (usually around 1/1,000 second of arc) that appears to be a star in an optical telescope. From these criteria comes the name "quasi-stellar radio source" which became shortened to "QSS" and "quasar". In their optical spectra, quasars display large redshifts, implying that they are very distant objects. If they are distant, however, they exhibit energy production very difficult to explain, for not only can the total energy output exceed that of large normal galaxies by 100 times, but the energy source must be very small — only a few light-days across — because their light and radio output can fluctuate significantly in just a few days!

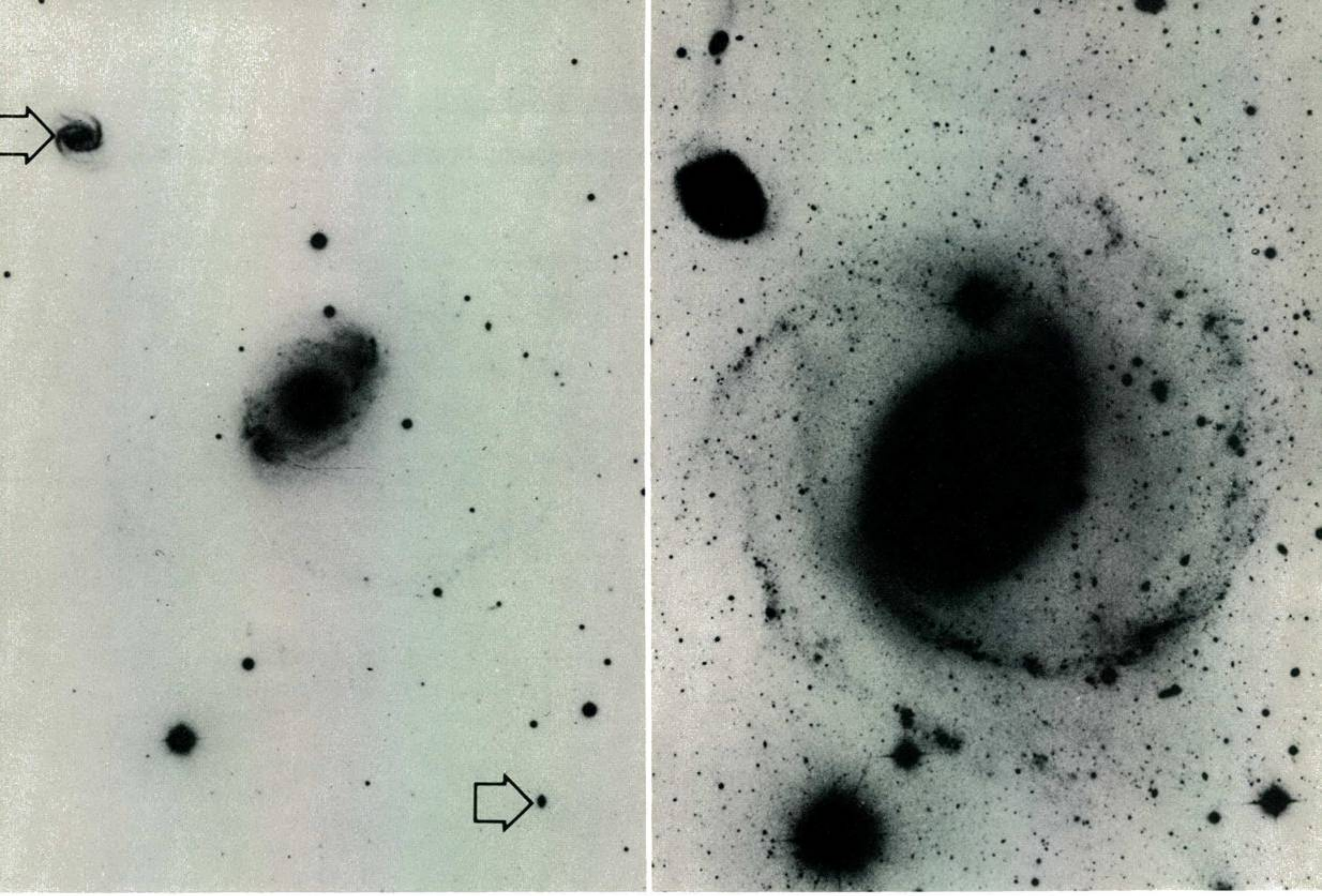
Explanations and theories for quasars range from "giant black holes in the cores of galaxies" to "chain reactions of supernovae" to "cores of newly formed galaxies in the early universe". Astronomers suspect that quasars are related to Seyfert galaxies (relatively normal galaxies with quasarlike cores) and BSOs — a class of high redshift objects that show no radio emission — which might be turned-off quasars.

Why, then, do the galaxy elongations not point directly to the quasars, but 30 degrees to the side? If they were thrown out many years ago, the galaxy would have rotated since then. Taking a reasonable estimate for the rotational speed of the galaxy, Arp got an ejection time of 10 million years — almost exactly the age of a quasaar.

It's easy to see why this case has caused so much controversy. Without a doubt it's difficult to explain. But if it's the only case, it's quite possible that the galaxy is just superimposed on the quasar, and that they really are a considerable distance apart. However, it turns out that there are other cases — several of them. The galaxy called NGC-7413 and quasar called 3C-455 are similar. Although there is no luminous filament — at least one hasn't been found so far --the isophotal lines are extended in a direction close to that of the quasar.

The controversy is, in fact, not restricted to

This 18-times enlargement of Hale Observatories plate PH-5858A (the same plate shown on the previous page) is reproduced as a negative to help you see the luminous bridge. Is it real? Astronomers cannot agree. But the implications, if the bridge really does connect these two, are profound. Photograph copyright © 1971 by California Institute of Technology and Carnegie Institution of Washington.



The Seyfert galaxy NGC-4151 appears in three different guises: At left in a short exposure, it shows the bright nucleus and inner arms. Note the small spiral galaxy at upper left and another small galaxy at lower right. The middle picture is a considerably "deeper" plate. Although the central regions of the galaxies are "burned out", the outer spiral arms now appear to lead up to each of two small galaxies. At right, a computer processed image reveals extra details suggesting a physical connection between NGC-4151 and its two "companions". Both small galaxies have redshifts quite different from the redshift of the main galaxy. (See the *Astrophysical Journal*, Nov. 15, 1977, for a complete description.) Photographs courtesy of Halton Arp, copyright ©1977 by Hale Observatories.

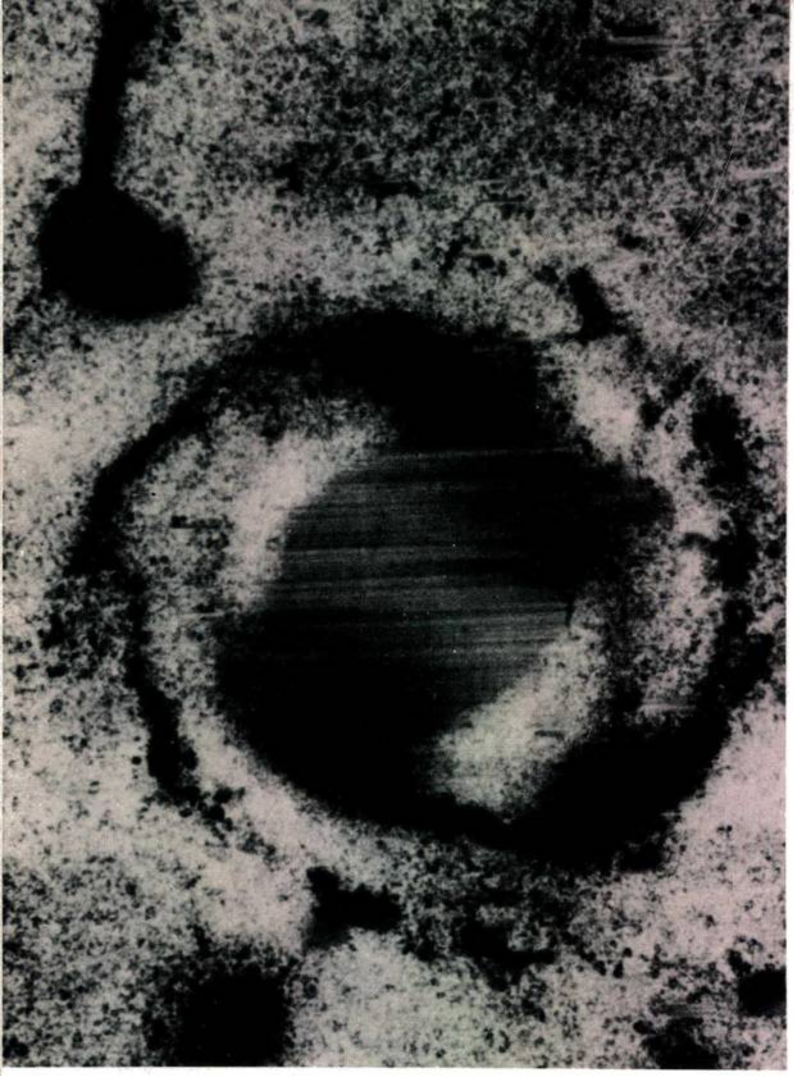
quasar-galaxy combinations; it also involves pairs of galaxies. In some cases it appears that galaxies have been ejected from galaxies. One is a system called NGC-4151. Like NGC-4319 (the galaxy we first looked at), this system also has two long dangling arms, and near each of these arms is a smaller galaxy. Both have redshifts quite different from that of the main galaxy.

Another case of a *discordant object* involves the galaxy NGC-7603. A long luminous filament curves out of it and appears to terminate on a second smaller galaxy. The larger galaxy has a recessional velocity just about half that of the companion's. The spatial separation implied by the redshifts is quite large — somewhere around 500 million light-years! Again we ask: Is it just a coincidence? Arp gives the following reasons why he does not think so: First, the larger galaxy is peculiar and disturbed. In short, it looks like a galaxy that could have ejected another galaxy. Second, the luminous filament is, itself, unusual. It ends exactly on the second galaxy — not a likely coincidence. Third, the ejected galaxy is also unusual. It has a faint halo which brightens slightly where the filament appears to join it.

Is this filament actually connected to the second galaxy? John Bahcall of Princeton University has examined it carefully and is sure that it isn't. He thinks it ends *just past* the second galaxy. Take a look yourself. As you can see, it's hard to tell.

Before going on we should mention a major problem in Arp's ejection theory. Let's suppose one of the quasars were ejected from the galaxy in a direction *away* from us. To conserve momentum, the second quasar would have been ejected *toward* us. It should, in fact, have a smaller redshift than the galaxy. So far, all discordant objects discovered have larger redshifts than their parents. We still don't know why.

To get a better perspective on the problem, let's go back a few years to see how the controversy started. Though Arp has been a leader in the field, he wasn't the first to discover a discordant object. Before he became interested in them several were known, but astronomers just assumed they were background objects and let it go at that. In 1966, Arp began an extensive study of peculiar galaxies, compiling his well-known **Atlas of Peculiar**

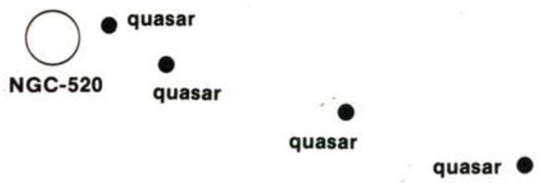


Galaxies. Dim galaxies with particularly large redshifts appeared in many cases to lie extremely close to these peculiar galaxies. Many of them occurred in pairs — one on each side of the peculiar galaxy. What caused this? On the basis of his observations, Arp formulated the ejection theory, but few astronomers were interested. Eventually, as he pointed out more and more cases, astronomers began to take interest.

Others observations seemed to agree with his ideas. For example, in 1969, Erik Holmberg of the Astronomical Observatory at Uppsala, Sweden, showed there was an excess of small companion galaxies around moderately bright spirals. In a large number of cases they occurred as pairs aligned along the minor (short) axis of the galaxy — almost as if they had been ejected.

Also, in 1971, Geoffrey Burbidge and others discovered that quasars fell closer, on the average, to bright galaxies than they would if they were randomly distributed. Out of 47 cases, they found four within seven minutes of arc of bright galaxies — a result that had only one chance in 250 of being accidental.

In 1971, Arp pointed out one of the most interesting examples of *apparent* ejection. Lying in an almost perfectly straight line are four quasars! Extending the line through them, Arp found it also passed through one of the brightest exploding objects in the sky, NGC-520. Coincidence? It's hard to say.



Consider the Pegasus Quint, a group of five galaxies that appear to be interacting with each other. When spectra of the individual galaxies were obtained, the redshifts stunned astronomers. One galaxy has a redshift quite different from the others. Perhaps the discordant one was just superimposed on the others. To check this possibility, Arp measured the H-II regions of each of the galaxies. H-II regions are vast clouds of glowing hydrogen gas useful because their sizes can be used as an indication of distance. If the discordant object turned out to be much closer to us (as the redshift indicated), its H-II regions should be much larger — eight times larger, in fact. Yet, when the measurements were made, all the H-II regions were approximately the same size.

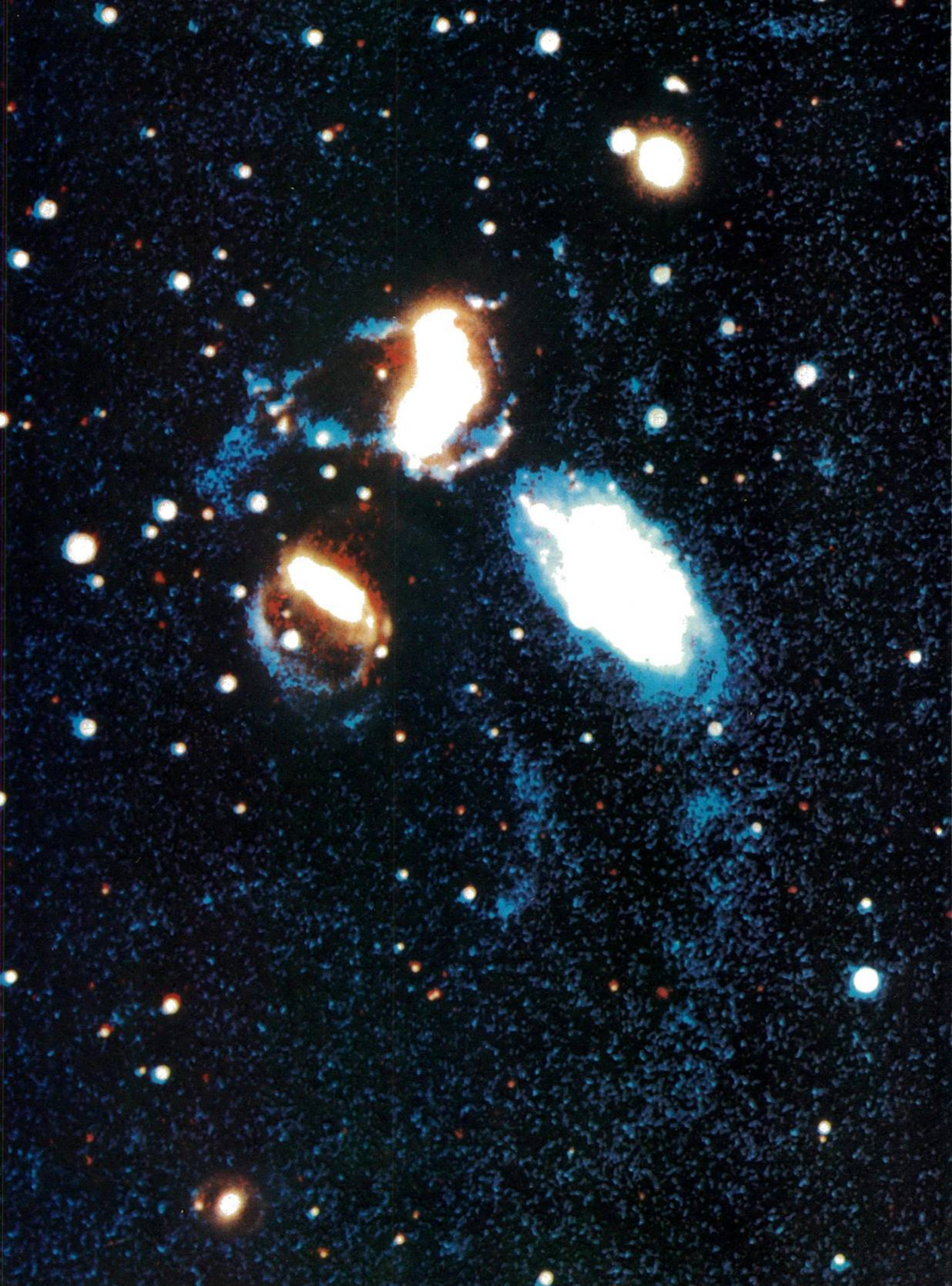
In addition there is also some indication of overlap. A long luminous strand coming out of the discordant galaxy seems to interact with one of the other galaxies.

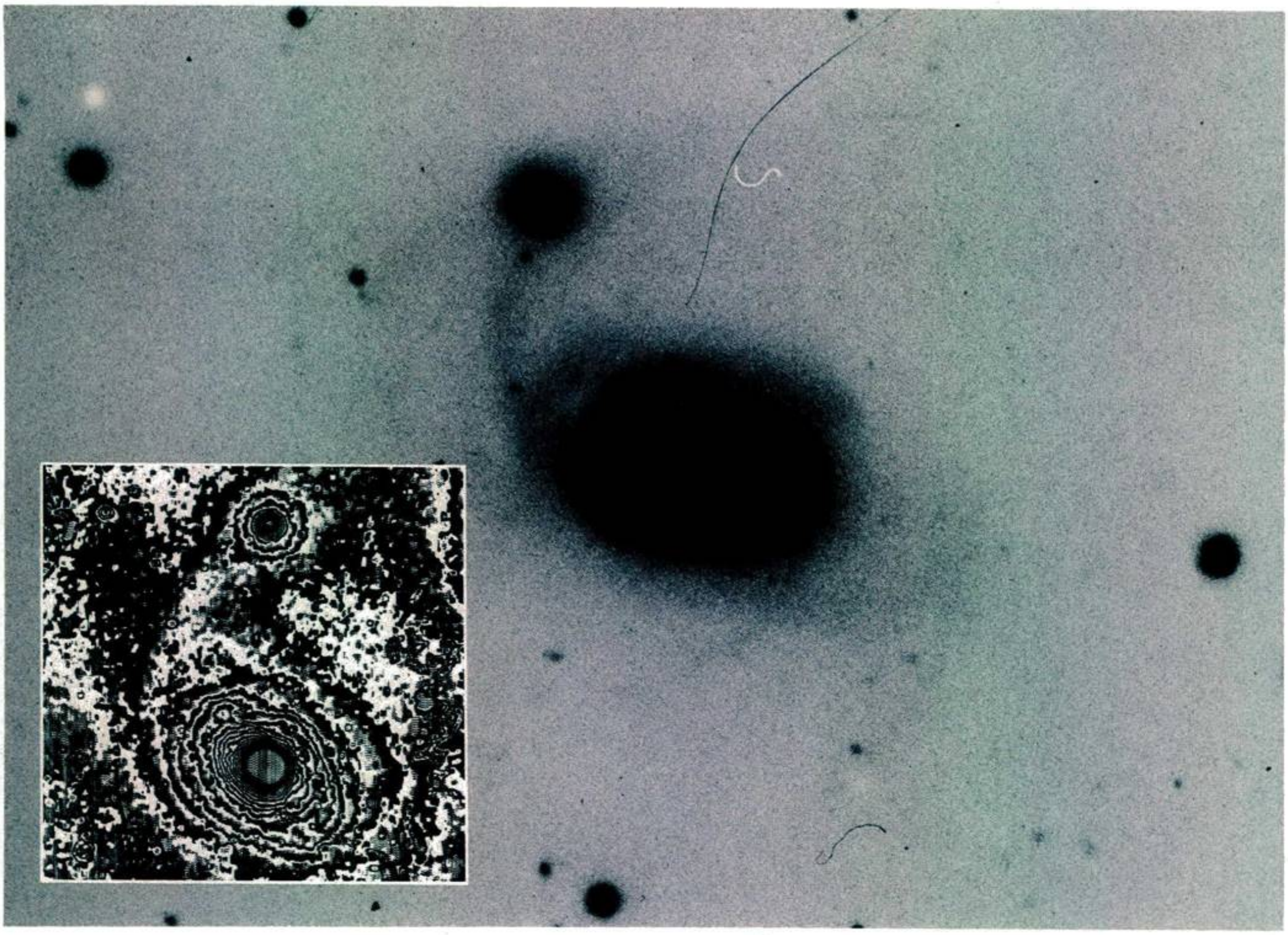
There is also conflicting evidence that the discordant object is not associated with the others. According to G. A. Tamman of Hale Observatories, individual stars can be seen in it (that is, it can be resolved), but they cannot be seen in any of the other four. He believes this galaxy is much closer than the others — in accord with its redshift distance. Indeed, he points out that it may actually be part of another nearby cluster.

A similar group is one called VV172 (shown on page 14). The second galaxy from the top has a much higher redshift than the others. If it is a coincidence, the probability is low.

Other clusters — particularly much larger ones — also pose problems. As long ago as 1962, Holmberg showed that the faint galaxies within the Virgo cluster have a slightly higher average redshift than the average bright spiral. Yet all these objects are at the same distance. A similar phenomena, though one involving different kinds of objects, also occurs in the Coma cluster.

The discoveries of Arp and others are interesting, but most astronomers still do not feel they are a threat to the Doppler interpretation of the redshift. The burden of proof still rests in showing a physical connection between discordant objects. One of the more vocal of this group is Bahcall, who has carefully examined Arp's cases and criticizes Arp's interpretation of most of them. Many do indeed seriously challenge the ejection hypothesis.





Left: The Pegasus Quint (also known as Stephan's Quintet) is a group of five galaxies that appear to be interacting with each other. This 200 inch telescope photo, made by combining an image taken in blue with an image taken in red light, shows the discrepant redshift galaxy as bluish in color. Its redshift is much lower than the other four galaxies. Above: NGC-7603 appears to have a long glowing filament that ends at, or near, a second smaller galaxy. But the redshift of the small galaxy implies it lies millions of light-years behind NGC-7603. The inset image shows an isophote tracing of this object. Photographs courtesy of Halton Arp, copyright © 1978 by Hale Observatories.

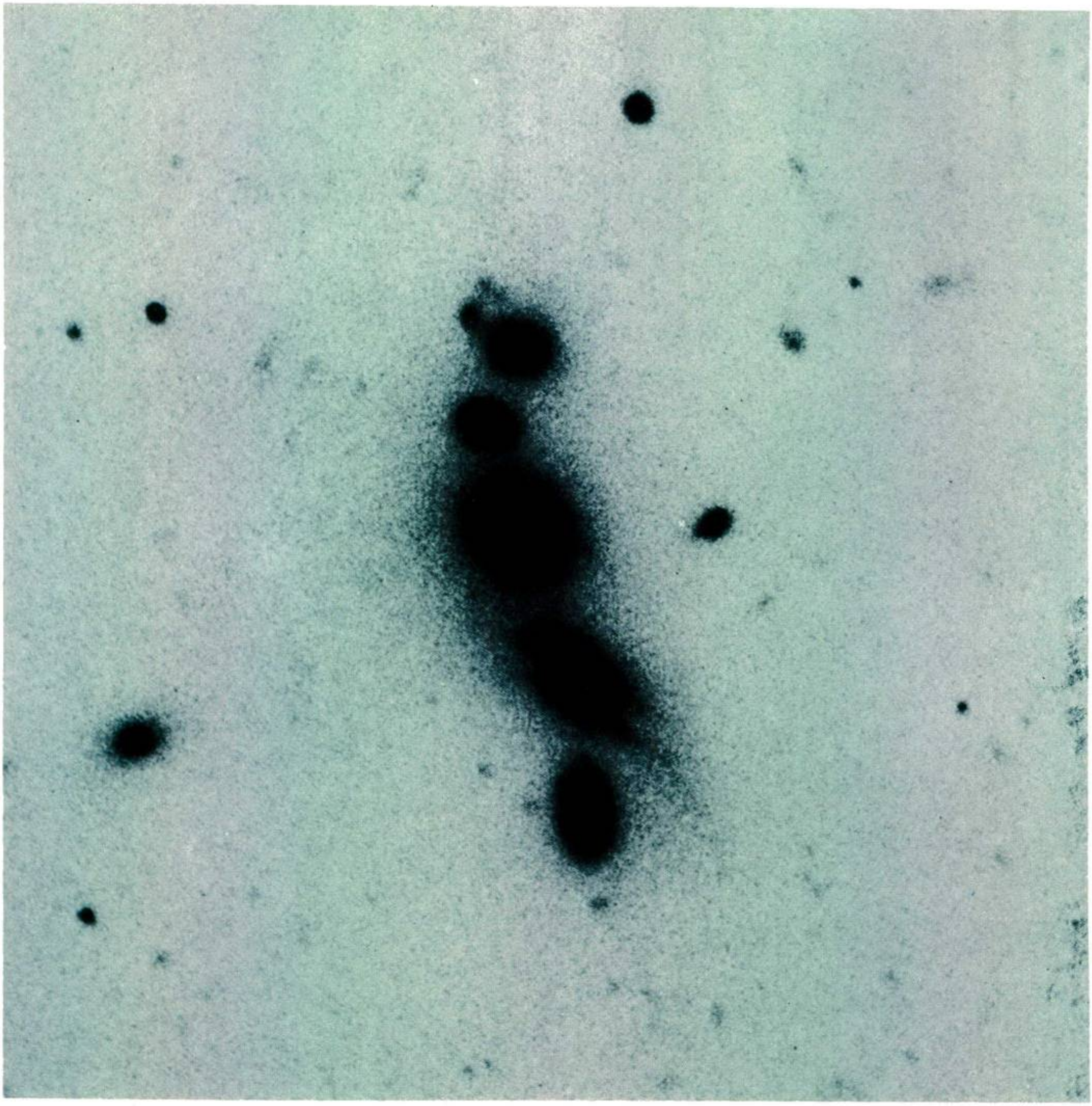
Is there really anything to this controversy? And if there is, who is correct? Though there does appear to be a problem, it may be years before we know the answer. Where only a few years ago there was almost unanimous agreement among astronomers as to the validity of the Doppler interpretation of the redshift, there is now some doubt.

Let's consider some of the ways the problem could be resolved. Since many of the discordant objects are quasars, we might ask: Is it possible that the redshift means something different for quasars than it does for galaxies? The trouble here is that there are groups of galaxies with quasars in them that have the same redshift. A compromise might be that there are two types of quasars. For the first type the conventional Doppler interpretation is valid, but for the second it is not. This would obviously create more problems than it would solve. We would have to postulate a new interpretation for the one class of quasar and explain why they were different from the other type.

Even when they are not discordant, quasars are an enigma. Their enormous redshifts indicate a recessional velocity greater than 90 percent that of light in some cases. This places them very close to the edge of our observable universe. Most galactic redshifts are less than half this.

There are also other problems with them. In 1971, a pair of radio sources within a quasar were discovered that appeared to be moving away from one another. Their redshifts indicated they were very close to the edge of our observable universe. Four months later they were checked again. During the interval they had separated by an incredible amount. Astronomers were shocked. Calculations were soon made (under the assumption, of course, that they were near the edge of the universe) and the results were amazing. The objects were found to be separating at a velocity equal to 10 times that of light.

Possible? Of course it isn't. We have ample proof that matter can travel only at speeds less than that of light. Are they close by, and their Doppler shift distances wrong, or are they some deviously false appearance? Certainly there is something here we don't know. Theorists have been busily devising theories and models in an effort to solve the



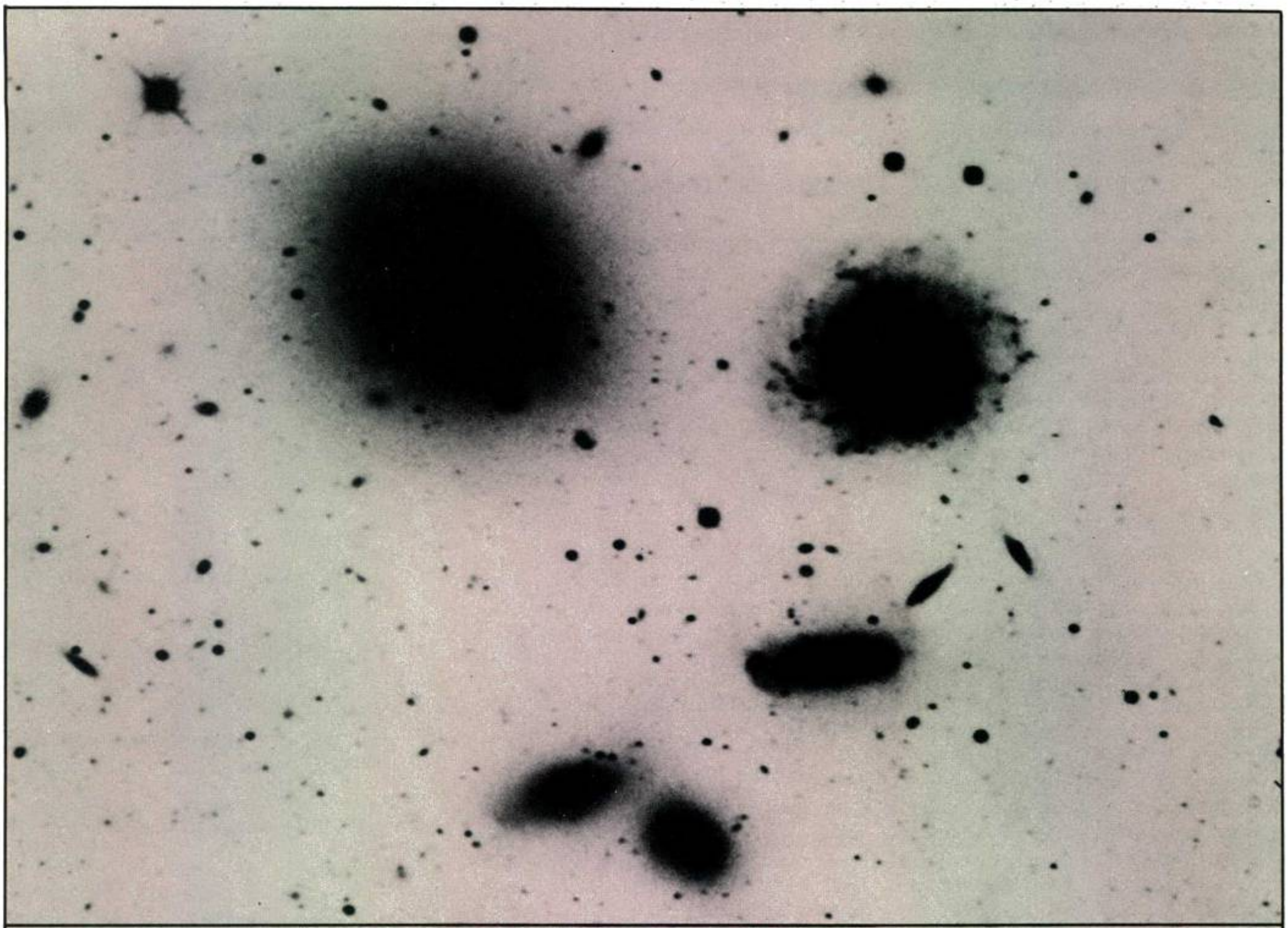
problem, but so far no solution is completely satisfactory.

We might, for example, propose the existence of a new undiscovered phenomenon, which would need a new law to explain it. Is it possible? Needless to say, it is. This new phenomenon might, for example, cause noticeable redshift effects over extremely long distances, though not affect things over shorter distances. This would mean that the redshift for most nearby objects would be predominantly of Doppler origin. But as the distance increased significantly, the new effect would begin to overshadow the Doppler contribution.

The only problem with this idea is that we know nothing of a phenomenon that might cause it. It's a poor solution, but we're free to speculate. Today many astronomers have a hunch that a really significant breakthough related to the redshift may be just around the corner. We'll just have to wait and see.

VV172 appears to be a physically connected chain of galaxies. But the galaxy second from the top has a redshift more than twice that of the others, placing it more than twice as far away as they are. Though possible, such an alignment coincidence is unlikely. This photograph, perhaps the best ever made of VV172, is a 16-times enlargement of a 90 minute exposure made with the 200 inch telescope. Photography courtesy of Halton Arp, copyright © 1978 by Hale Observatories.

Barry Parker is an associate professor of physics and astronomy at Idaho State University where he has taught courses in descriptive astronomy, astrophysics, cosmology and astrophotography. His main interests are black holes and cosmology, and he is currently writing a popular level book on the latter.



NGC-1199

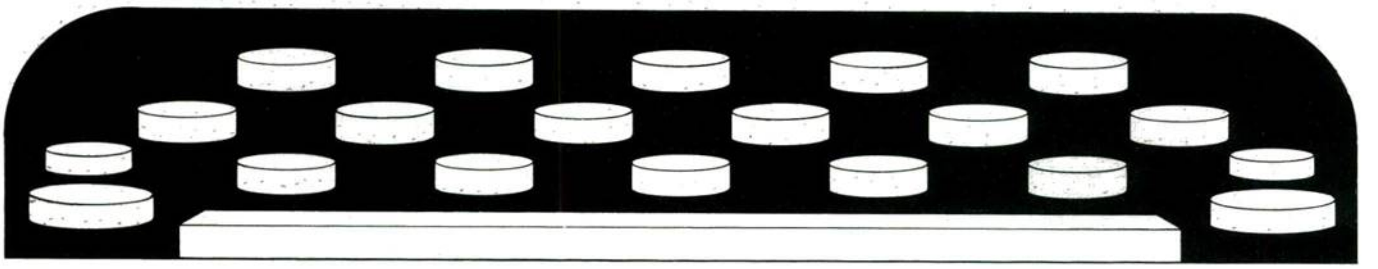
by

Halton M. Arp

The E galaxy NGC-1199 is the brightest member of a small cluster of galaxies. Among its companions is a galaxy so compact that, at first glance, it looks like a star. Such a galaxy is not likely to appear by itself in space, nor is it part of a more distant cluster of galaxies. It would be expected — by its appearance — to be a member of the small group of bright galaxies of which NGC-1199 is the dominant member. But the redshift of the compact peculiar galaxy is 13,300km per second, whereas the redshift of the central NGC-1199 galaxy is only 2,600km per second.

In the beginning, an investigation of possible interaction between the compact galaxy and NGC-1199 revealed a circular shadow around the compact as if it were in front of NGC-1199 and absorbing the light of the E galaxy behind it. From 1965 to 1976, I photographed it with the 200 inch telescope at Palomar, the four meter telescope at Kitt Peak National Observatory and the four meter telescope at Cerro-Tololo Interamerican Observatory until I was certain that I had the best possible photographic representation of this silhouetted galaxy. Finally, I measured the absorption ring with the new linear response Silicon Image Tube Spectrograph on the 200 inch telescope.

With all these techniques, I now believe that I have demonstrated that the compact galaxy is in front of the E galaxy, despite its much higher redshift. Like other examples of galaxies and quasars with anomalously high redshifts, the physical mechanism for producing this intrinsic redshift is not presently known.



IN FOCUS

Editors' Note: On page 44 of the July 1978 issue, the Maksutov corrector shows a corrector that must be slightly aspheric on one surface. Normally correctors are made with both surfaces spherical; these correctors either diverge or converge all the light rays, but by different amounts. Schmidt correctors are usually made as shown with the thinnest zone at 0.71 the radius of the corrector. However, there are many alternate forms, some of which diverge or converge all the rays.

Sir / First, I want to tell you how much I enjoy getting ASTRONOMY each month. I always get a lot of satisfaction out of reading it.

I was particularly interested in the photograph that appeared on page 20 of your June 1978 issue. This picture, although not in great detail, was very thought provoking indeed. I thought you might be able to tell me where I can obtain a print of this Voyager relay. Perhaps you have the address of a NASA official who could direct me to such information.

ROBERT S. MORTON
Cuthbert, Ga.

Mr. Morton / Judging by the inquiries we've received, your interest in the Earth/moon shot taken by Voyager was shared by many of our readers. You may obtain the photo by writing to:

Jet Propulsion Laboratory
Pasadena, Calif. 91103

Here at ASTRONOMY we often receive photograph requests, but due to the volume of mail we're unable to answer each letter personally. If you see a photograph that you'd like a copy of, your best bet would be to write the institution involved. Here is a list of the major ones:

Public Affairs Office
Audio-Visual Branch
NASA Headquarters
400 Maryland Ave. S.W.
Washington, D.C. 20546

Hale Observatories
c/o California Institute of Technology Bookstore
1201 E. California Blvd.
Pasadena, Calif. 91109

Catalog-Public Information Office
Kitt Peak National Observatory
P.O. Box 26625
Tucson, Ariz. 85726

Lick Observatory
University of California
Santa Cruz, Calif. 95060

Photograph Service Dept.
Yerkes Observatory
Williams Bay, Wisc. 53191

You can write to any of these institutions for information or catalogs (some for a small fee). Prices for slides will differ from one observatory to another.

Sir / I enjoyed very much Henry Phillips' article on the spring constellations in your April issue. He has persuaded me, usually a naked eye stargazer, to take out my binoculars for a look at the Beehive and other clusters. Perhaps beginners need to be told specifically that this spring the planet Saturn is complicating the "sickle" in Leo!

Phillips writes, "Arcturus is the fourth brightest star in the entire sky...." In the **1978 World Almanac's** star tables, it is the fifth brightest. But I think it is third! As the splendor of Venus among the planets repeatedly astonishes me, so does the gleaming brightness of Arcturus among the stars. I consider it the brightest star in the northern half of the heavens, surpassed only by Sirius and Canopus in the southern half.

Leslie Peltier agrees with this. In **Guideposts to the Stars**, page 45, he says:

> "There has long been a vast amount of disagreement among observers concerning the relative brightness of Arcturus, Vega and Capella. Although only a fraction of a magnitude separates the three, recent measures place Arcturus in the lead and make it second only to Sirius among the bright stars to be seen from midnorthern latitudes. Vega is slightly fainter than Arcturus, and Capella follows very closely."

POWELL HALL JR.
Englishtown, N.J.

Mr. Hall / We agree with you and Leslie Peltier on the relative brightnesses of Arcturus, Vega and Capella. However, Arcturus is exceeded in brightness by Sirius, Canopus and Alpha Centauri, making it number four in the sky! We use the following visual magnitudes: Sirius, -1.42; Canopus, -0.72; Alpha Centauri, -0.27; Arcturus, -0.06; Vega, +0.04; Capella, +0.05.

Sir / For many years I've been fascinated by galaxies, and have been interested in painting them in their natural colors.

I'd like to know where I can obtain color photos of galaxies. The only ones I've seen in color are M-31 and M-33, and I suspect that many more have been photographed in color. (I do have the April 1978 issue of ASTRONOMY with NGC-253 on the cover.)

Secondly, are there any other atlases of galaxies besides the **Hubble Atlas of Galaxies**, which I have? I am especially interested in obtaining photos of galaxies of the southern constellations. So far, the photos of southern galaxies I've seen seem to show that the southern sky has many more barred spirals and unusual galaxies such as lenticular spirals, etc. than the northern sky. Is this so?

RICHARD A. FRANK
Passaic, N.J.

Mr. Frank / Some of the newest and nicest color galaxy photos we know of were taken at Kitt Peak and published in the March 1977 issue of ASTRON—OMY. Beyond those, however, there are very few because galaxies are difficult to photograph. Hale Observatories and the U.S. Naval Observatory (the source of the NGC-253 photo) have between them also released M-82, NGC-5907, NGC-7331 and M-51, but these pictures fail to show much faint detail. Kitt Peak has color pictures of the Large Magellanic Cloud and NGC-5128 available.

The **Hubble Atlas** *(available from Willmann-Bell Inc., P.O. Box 3125, Dept. A, Richmond, Va. 23235 for $16.00) is the only galaxy atlas we know that is available to the public. It is, we're sure you'll agree, an amazingly beautiful book.*

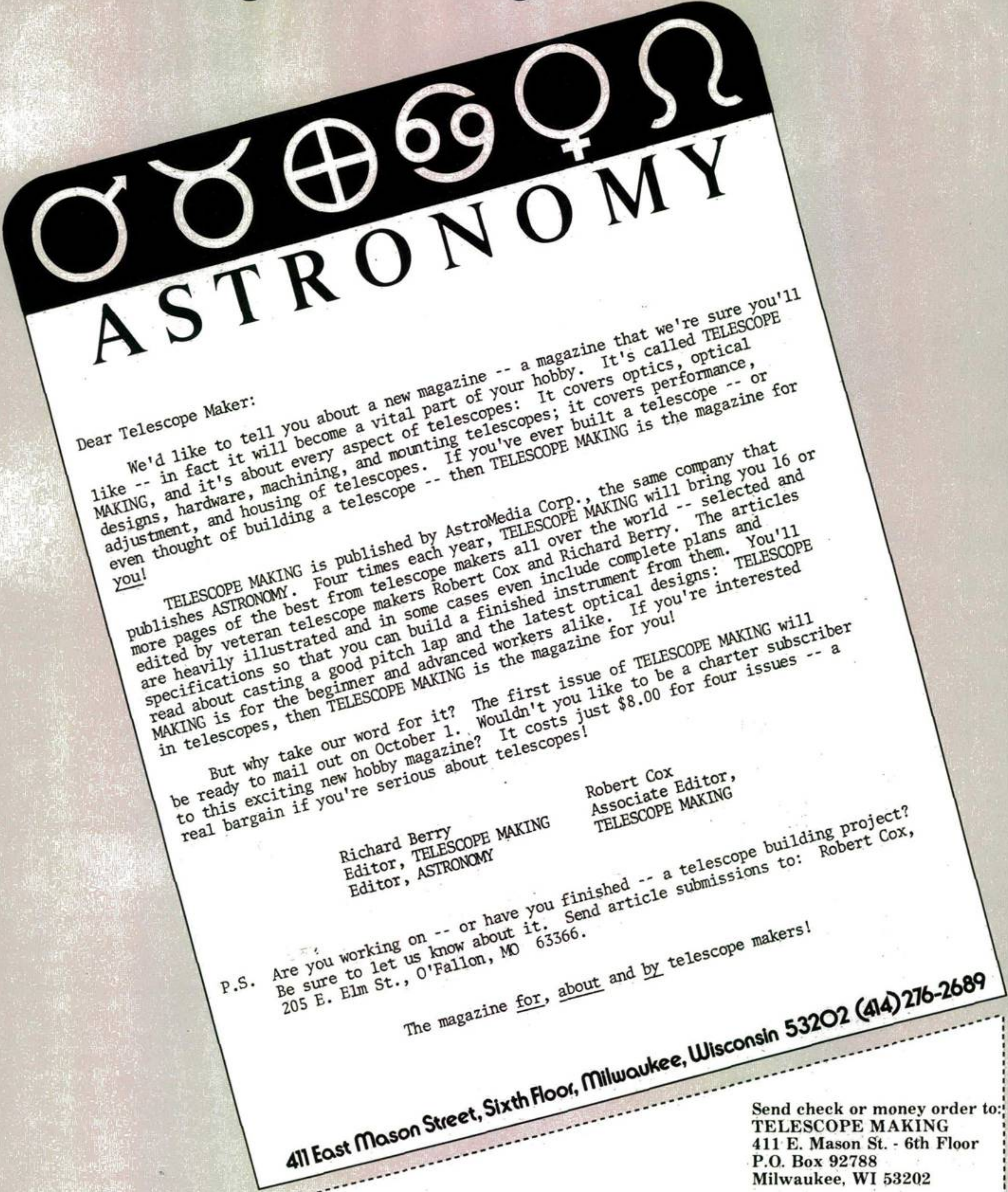
Finally, the southern hemisphere doesn't have an excess of unusual galaxies. In releasing pictures for distribution, southern observatories have tended to choose the more spectacular objects.

We hope that observatories will sense the growing public interest in the magnificent pictures just waiting to be taken — and respond by making more new and better photos available.

Sir / There is a kind of haze hanging over the subject of what portion of a "wave" can or should be specified for the accuracy of a mirror. In shopping around for good telescope optics, I've found the haze difficult to penetrate. Anyone who researches the market has only one objective rule to use: The less a mirror varies from a perfect

In Focus *continued on page 70*

Announcing a New Magazine . . . .



ASTRONOMY

Dear Telescope Maker:

We'd like to tell you about a new magazine -- a magazine that we're sure you'll like -- in fact it will become a vital part of your hobby. It's called TELESCOPE MAKING, and it's about every aspect of telescopes: It covers optics, optical designs, hardware, machining, and mounting telescopes; it covers performance, adjustment, and housing of telescopes. If you've ever built a telescope -- or even thought of building a telescope -- then TELESCOPE MAKING is the magazine for you!

TELESCOPE MAKING is published by AstroMedia Corp., the same company that publishes ASTRONOMY. Four times each year, TELESCOPE MAKING will bring you 16 or more pages of the best from telescope makers all over the world -- selected and edited by veteran telescope makers Robert Cox and Richard Berry. The articles are heavily illustrated and in some cases even include complete plans and specifications so that you can build a finished instrument from them. You'll read about casting a good pitch lap and the latest optical designs: TELESCOPE MAKING is for the beginner and advanced workers alike. If you're interested in telescopes, then TELESCOPE MAKING is the magazine for you!

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Richard Berry
Editor, TELESCOPE MAKING
Editor, ASTRONOMY

Robert Cox
Associate Editor,
TELESCOPE MAKING

P.S. Are you working on -- or have you finished -- a telescope building project? Be sure to let us know about it. Send article submissions to: Robert Cox, 205 E. Elm St., O'Fallon, MO 63366.

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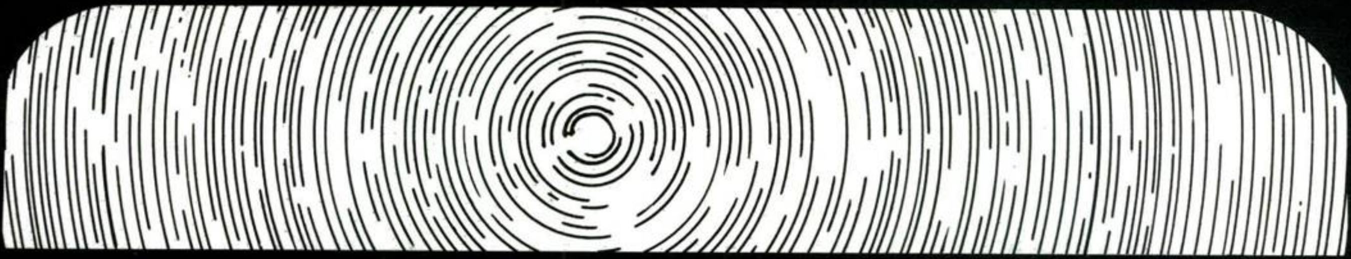


The Great Spiral:

Our Milky Way

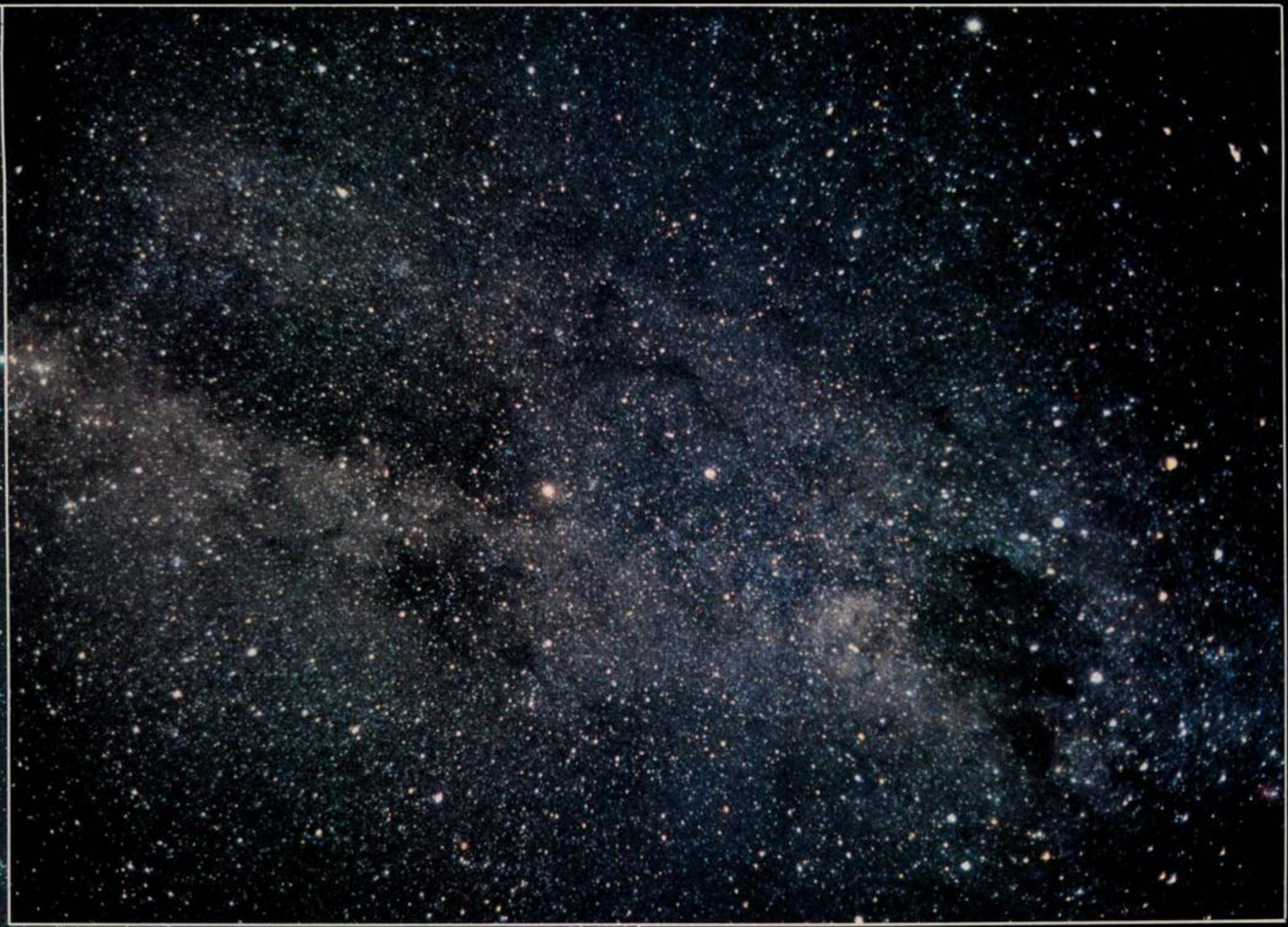
Galileo made the breakthrough discovery: The Milky Way consists of innumerable stars fainter than the eye can see. Through the rest of the 16th century, the 17th and the first half of the 18th, no other discovery so revealing was made, though the basic shape of the galaxy was defined by William Herschel and some crude guesses were made about its size. In a very real sense, astronomers had other — more important —things to do: They had to find out how large the solar system is, and what the planets are and how they move about the sun; they had to count and catalog the stars, and then measure how far away they are; they had to systematically explore the heavens to discover previously unsuspected planets and asteroids, and find double stars, clusters of stars and nebulae. The question of the Milky Way was too big and complicated for those times.

Today, however, 50 years of hard work have revealed much about the structure of our galaxy. On any clear night, you can look up — taking advantage of knowledge no prior generation has had. And you can appreciate what a grand system our galaxy truly is.

The Milky Way is an edge-on view into a giant flattened disk of stars, gas, dust and radiation 100,000 light-years in diameter and 3,000 light-years thick. It appears as a band around the sky because it is so thin relative to its diameter. At its center lies a somewhat flattened nuclear bulge, some 10,000 light-years thick and 13,000 light-years in diameter. Surrounding the disk and nucleus is a tenuous halo of stars and globular clusters that extends 100,000 light-years in all directions, and might easily be twice as large. The galaxy contains around 200 billion stars and emits the light of 20 billion suns. The sun circles the center of the galaxy in roughly 225 million years. The sun's speed around the center is 250km per second (about one-half million m.p.h.) in the direction of the constellation Cygnus. Relative to the average motion of nearby stars, the sun is drifting slightly north and in toward the center of the Milky Way, toward the constellation Hercules. This drift means the sun moves about the diameter of Earth's orbit — relative to the nearby stars — in eight months. The motion around the galactic center, which the sun shares with nearby stars, is some 15 times greater.

From our location roughly 33,000 light-years from the center, we can see 2,000 or 3,000 light-years into our galaxy in most directions,

Left: The Lagoon nebula is a great cloud of gas surrounding a brilliant — and very young — star cluster. It lies some 4,500 light-years distant in the approximate direction of the galactic center. Photograph by Greg Griffith. Right: Nestled into the star fields of Sagittarius, the Lagoon is far from alone in this rich region of sky. Nearby the Trifid shines red and blue, and the region abounds in small star clusters. Photograph by Dennis Stayer.

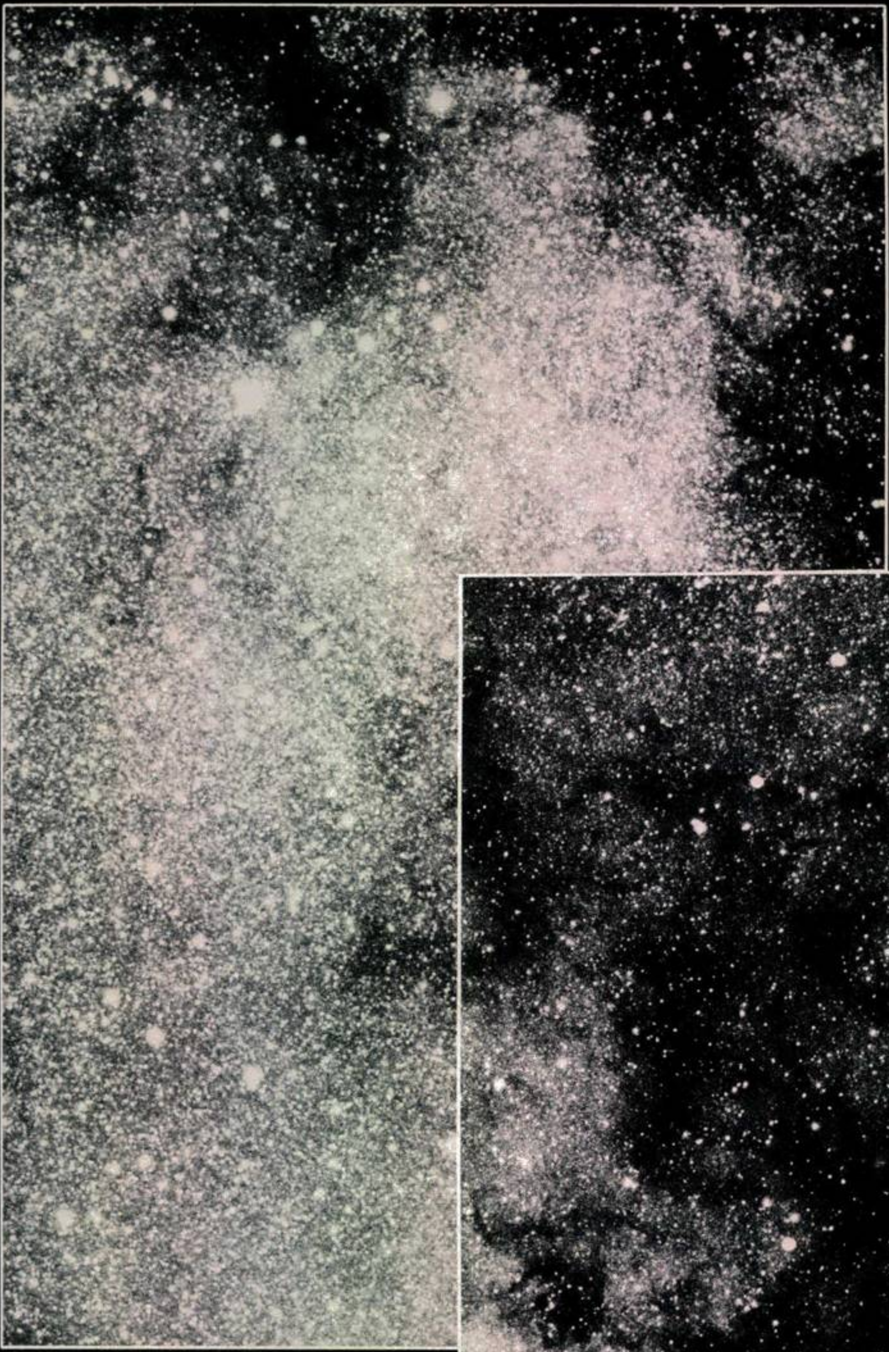


How lucky we'd be if we could look into the Milky Way and penetrate deep into its secrets, as we can with our galaxy's nearest neighbor, the Large Magellanic Cloud (shown at left). Because we see it face on and it contains relatively little obscuring dust, it has no secrets from the telescopes of astronomers. But our own galaxy is full of dustclouds, as well as countless stars. Photograph by Ronald Royer. In the southern Milky Way (above), nearly opaque clouds overlie a dense starry background. We are limited to seeing only the nearest parts of our own spiral arm and parts of the two nearest arms in our own galaxy. Photograph by James Janesick.

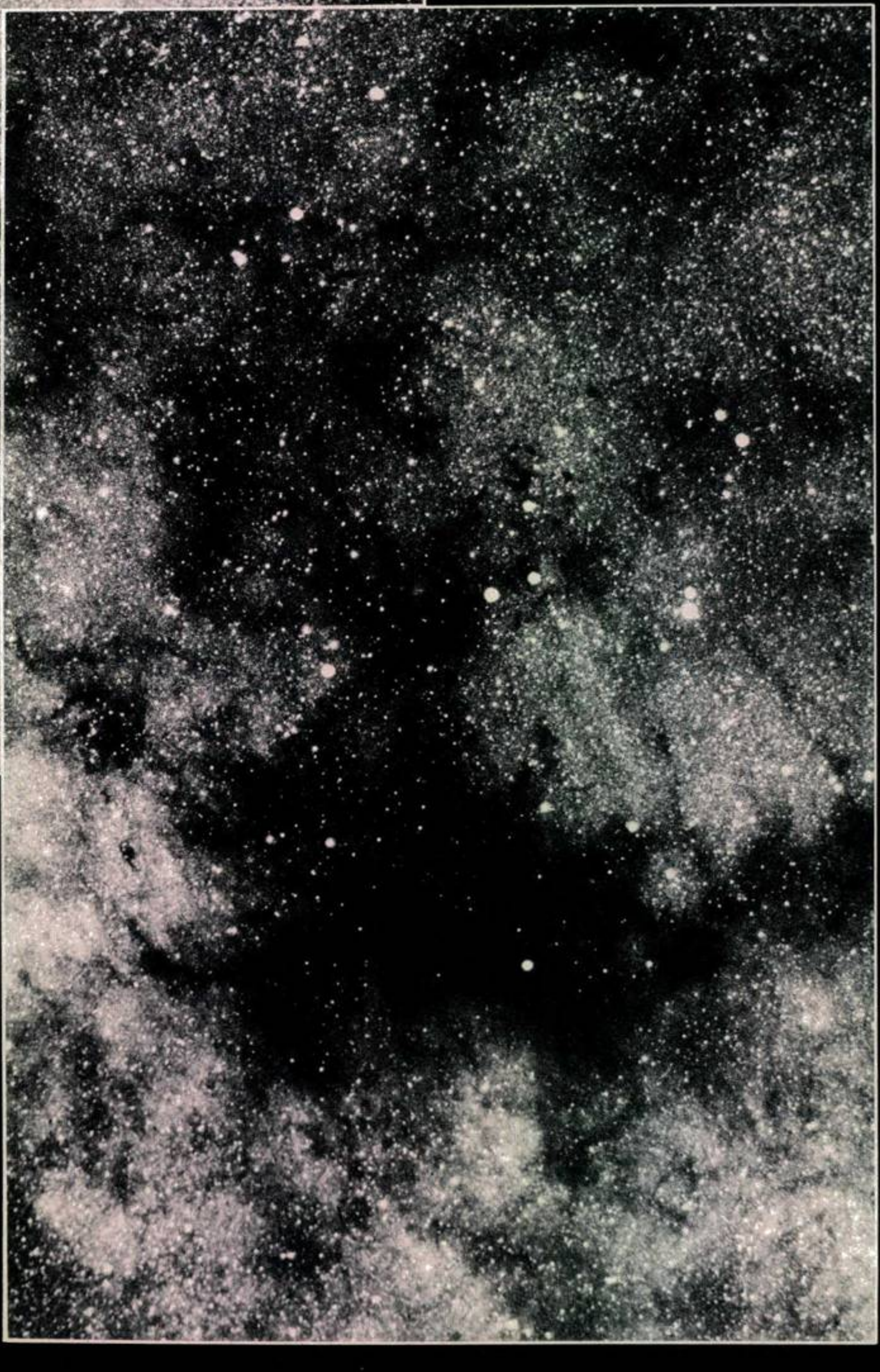
though in some places the view is blocked much closer to home. The sun is located along the inside edge of the Cygnus spiral arm which we can trace some 3,000 light-years as a gently curving arc. Looking out from the galactic center toward Perseus and Auriga, we can see the Perseus arm; looking inward we can trace an inner arm several thousand light-years. When we look inward, we see dark clouds of interstellar dust and gas that line the inside edge of our own spiral arm. We know of another inner arm — the Sagittarius arm — and can trace its arc several thousand light-years, mainly by peeping through cracks in the absorbing clouds. Around half of the Milky Way circle, from Cygnus to Crux, dark interstellar clouds — some isolated, some connected and continuous — form the Great Rift, splitting the Milky Way down the middle. The clouds may be up to 50 light-years

Text *continued on page 27*

Several hundred globular clusters circle about our galaxy. They are ancient, huge systems of stars, perhaps a million as in this specimen known as Omega Centauri. Located some 17,000 light-years from Earth, Omega Centauri is readily visible by naked eye, and is impressive even when seen in a very small telescope. But, its declination is 47 degrees south, making it difficult to see from the northern states. Photograph by Ben Mayer.

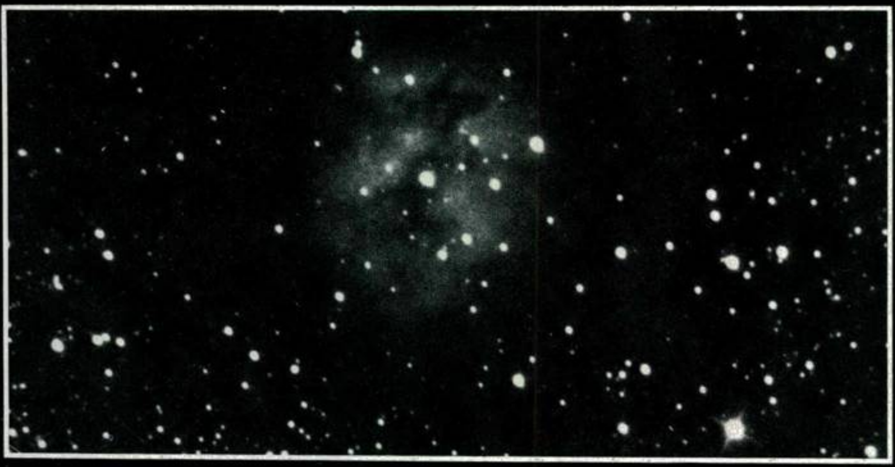


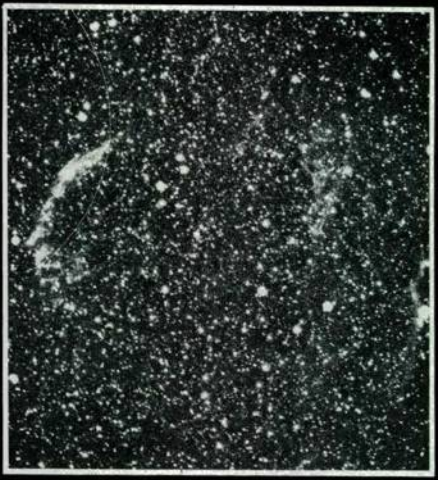
The Scutum starcloud is truly one of the splendors of the northern sky! East (left) of the main body of the starcloud you can see the open cluster M-11, almost hidden by the stars around it. Also look at the incursions of dark nebulae around the starcloud; these dark nebulae are in front of — and blocking — far more extensive fields of stars! Indeed, if the dark clouds weren't there, this whole field would be ablaze with swarms of stars richer than the richest parts of the Scutum cloud. Photograph by Richard Berry.

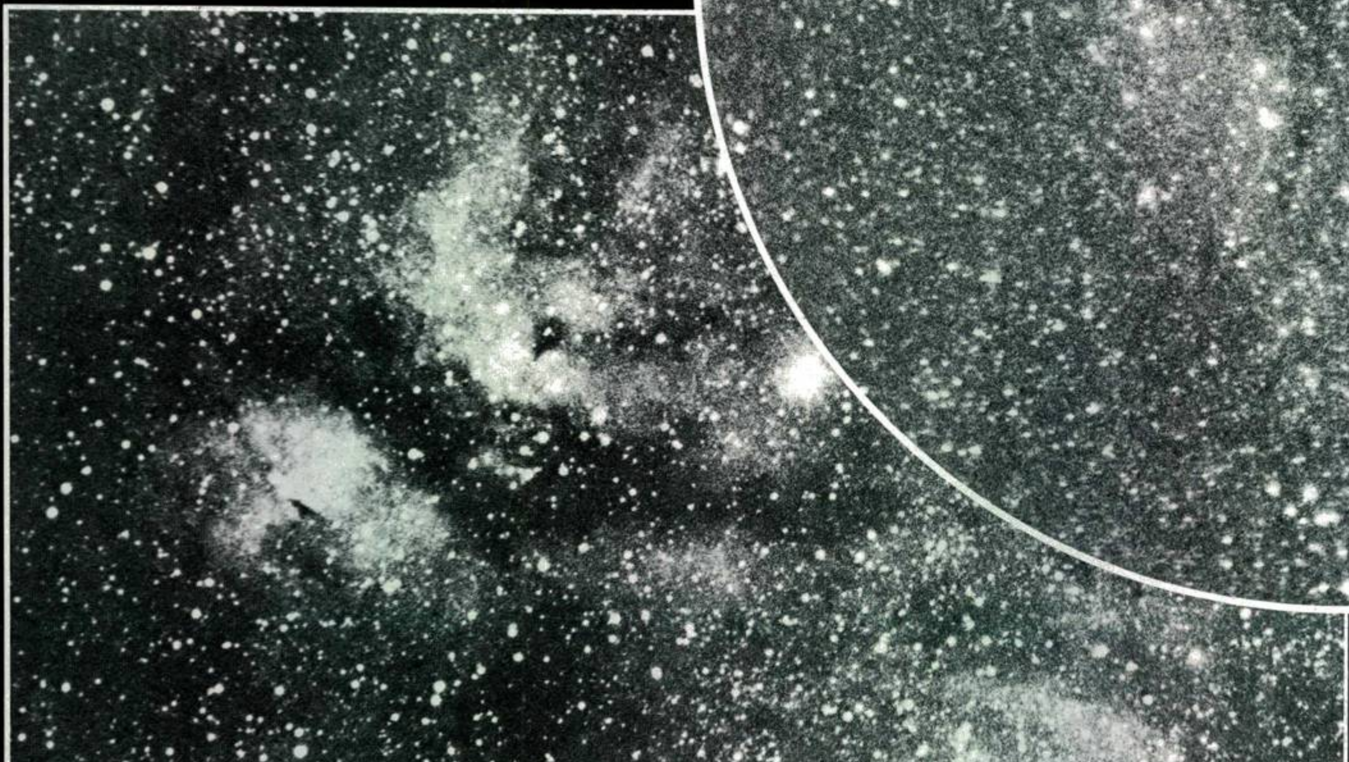


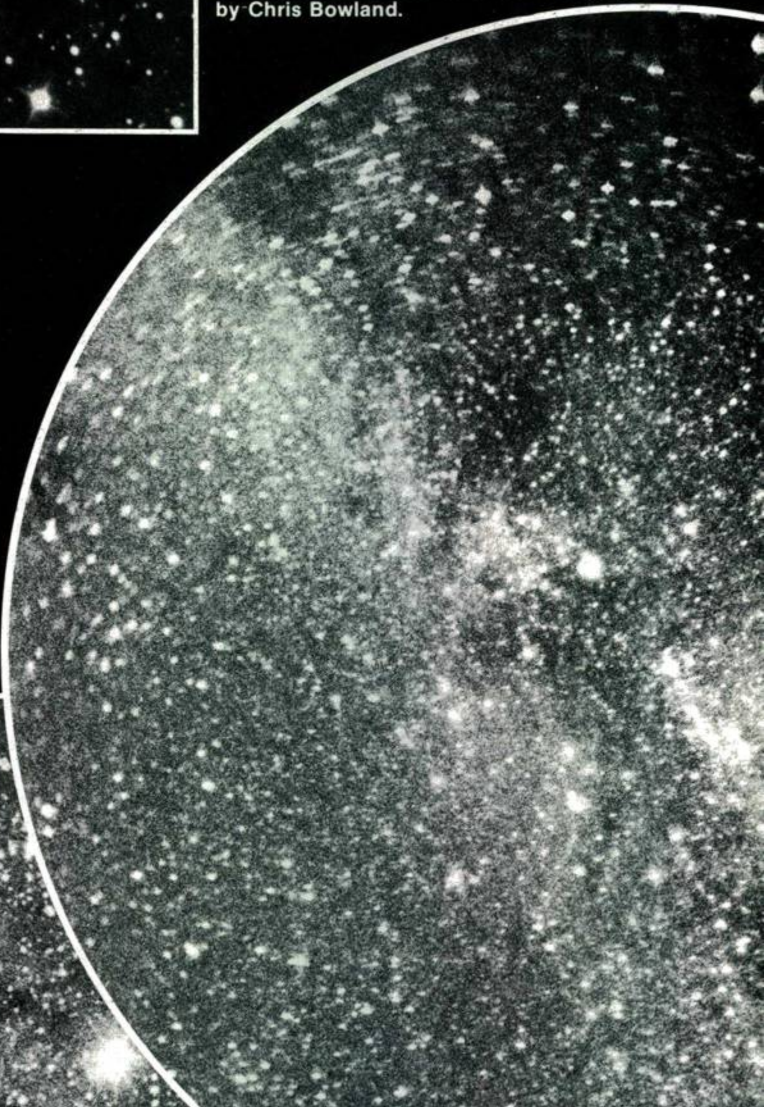
Ophiuchus, Sagittarius and Scorpio abound in dark nebulae. Sprawling across this entire picture are huge dark masses; silhouetted against stars are smaller nebulae that stretch into fantastic shapes. Tiny, almost inky black clouds of dust look like nebular knots pulled tight, opaque to the stars beyond. Barnard's famous "S" nebula lies slightly above center right. Underlying the entire field is a rich background of stars whose light cannot reach us. Photograph by J. A. Farrell.

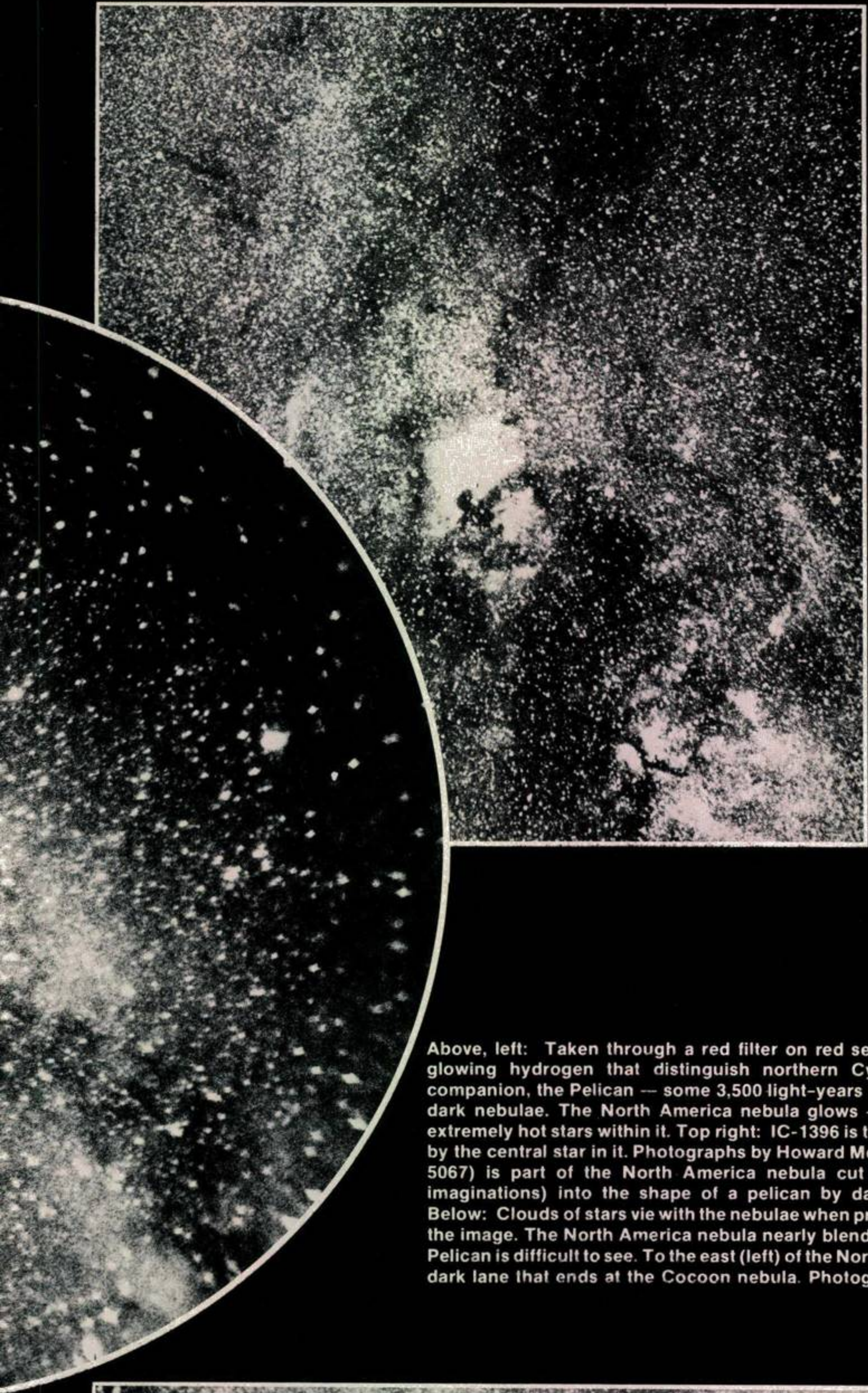
The round picture (below) stretches from northern Aquila to Cepheus — is a region so full that just scanning across it slowly with binoculars or a small wide field telescope is breathtaking. Photograph by Gordon Solberg. Top left: Tucked away at the end of a dark lane in Cygnus lies the Cocoon nebula, IC-5146. Photograph by Greg Griffith. Middle left: The Cygnus Loop (some 2,500 light-years from us) is the remnant of a supernova explosion. The bright star is 52 Cygni. Photograph by Robert Flory. Bottom left: Near Gamma Cygni lies a complex of emission nebulae, dark nebulae and star clusters. Photograph by Chris Bowland.

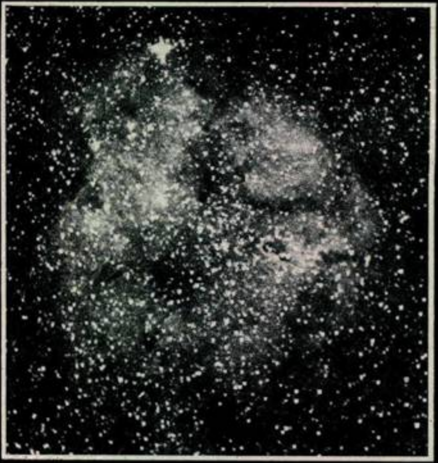


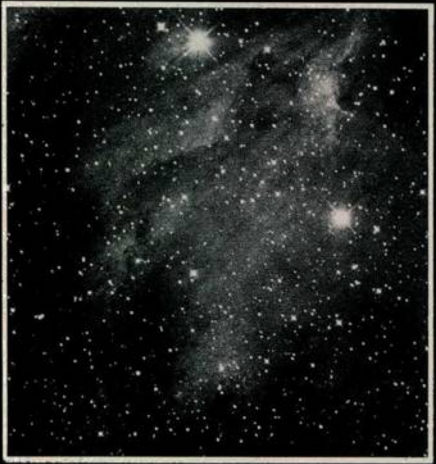




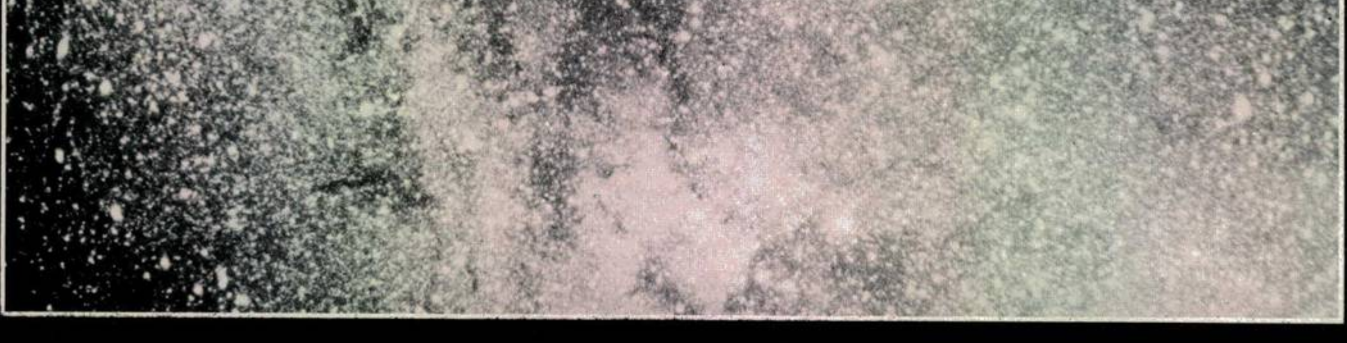


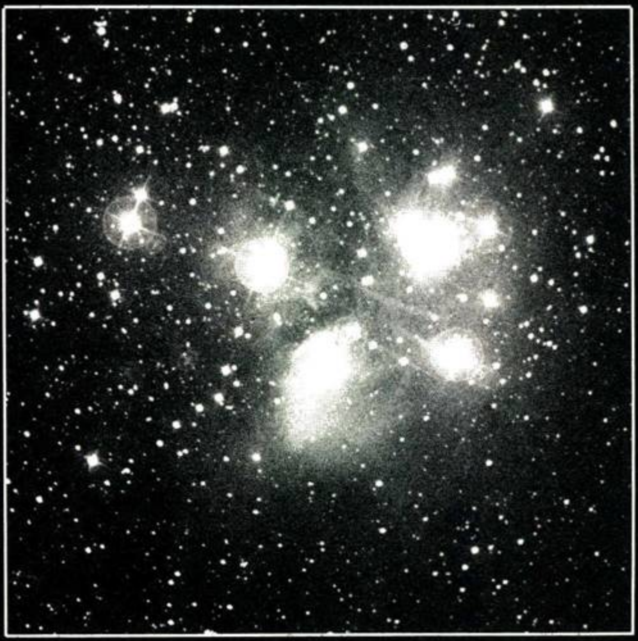


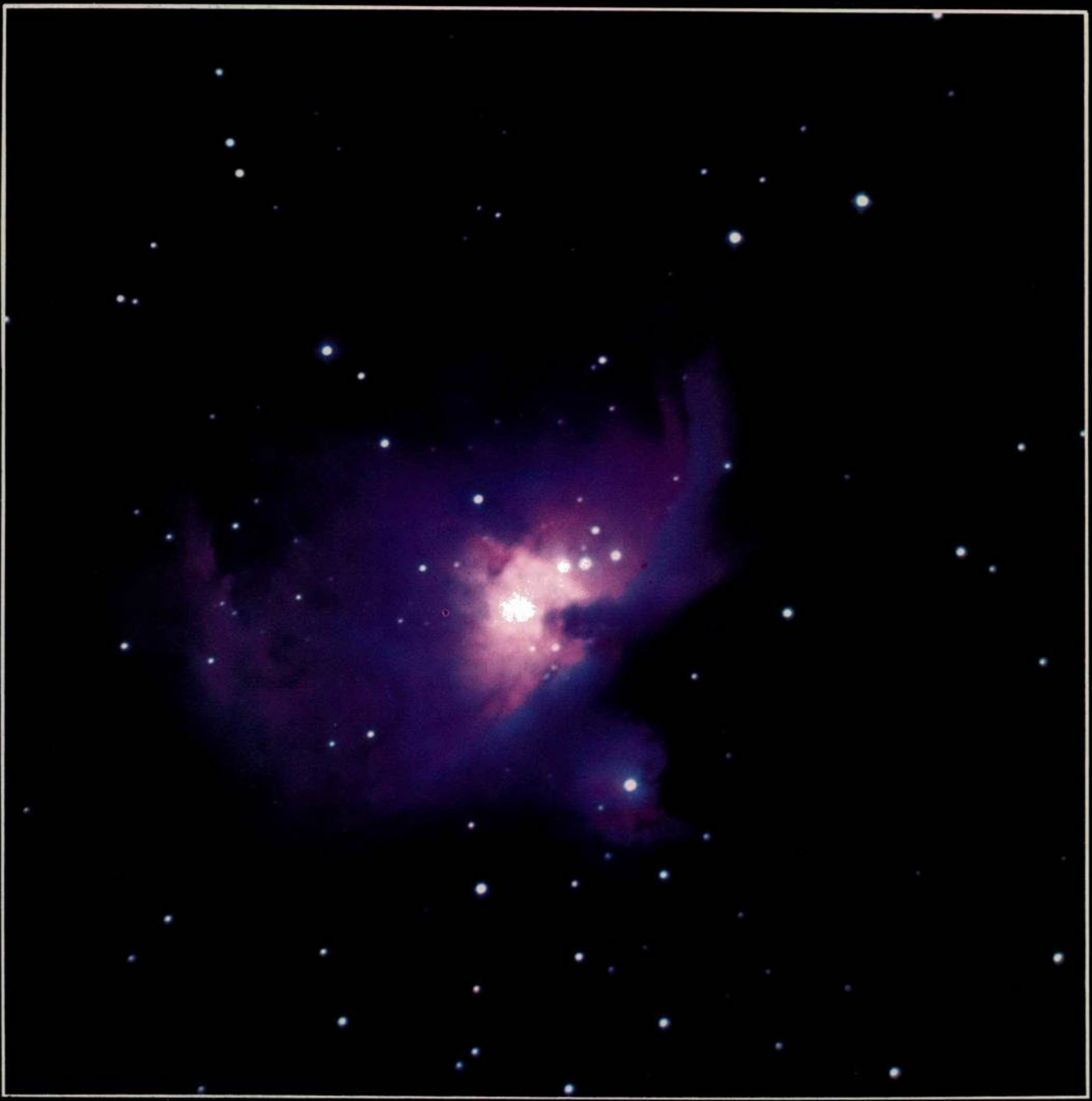




Above, left: Taken through a red filter on red sensitive film, this picture shows the clouds of glowing hydrogen that distinguish northern Cygnus. The North America nebula and its companion, the Pelican — some 3,500 light-years from Earth — shine through gaps in overlying dark nebulae. The North America nebula glows — as all H-II regions do — from the light of extremely hot stars within it. Top right: IC-1396 is the circular glowing region — an H-II region lit by the central star in it. Photographs by Howard McCallon. Lower right: The Pelican nebula (IC-5067) is part of the North America nebula cut off and fashioned (at least to our Earthly imaginations) into the shape of a pelican by dark nebulae. Photograph by Walter Hamler. Below: Clouds of stars vie with the nebulae when predominantly blue, green and yellow light form the image. The North America nebula nearly blends into the starclouds to the northeast, and the Pelican is difficult to see. To the east (left) of the North America nebula is a thin dark streak; this is a dark lane that ends at the Cocoon nebula. Photograph by William Morrow.







The winter sky offers many rewards to northern observers who can bear the cold. Opposite, top left: M-37 is only one of many brilliant open clusters that dot the winter sky, the impression of brilliance seeming greater sometimes when the air is the coldest. Photograph by Walter Hamler. Top right: Another cluster, the Pleiades, is bathed in material that reflects the light of stars. On the clearest of nights, far from city lights, this nebula can be glimpsed with a telescope. Photograph by Frank Melsheimer. Center left: The sky near Zeta and Sigma Orionis holds an amazing sight for intrepid photographers: The Reflection nebula (NGC-2024) reflects the light of Zeta, while the Horsehead — a dark nebula — is silhouetted against the emission nebula IC-434. By comparing the number of stars on the left side of the picture with the number on the right side, the extent of the dark material becomes evident. Photograph by Martin Germano. Center right: The California nebula (NGC-1499) glows from the light of the inconspicuous, but intensely hot, star near it. Photograph by David Healy. Bottom: Star clusters associate with gas and hot stars in Auriga. Looking almost directly away from the center of the galaxy, this region is nearly free of absorbing material. M-36 and M-38 hobnob with NGC-1931 (middle), NGC-1893 (with the dark center), and IC-405 (farthest right) which surrounds the famous "runaway star" AE Aurigae — an escapee from the Orion star formation complex. Photograph by J.A. Farrell. Above: The prize of the winter sky, and heart of the active star making complex in Orion, is the Orion nebula. Lying some 1,500 light-years from the sun, this entire region is such a hotbed of activity that it would be noticed by astronomers looking toward us from other galaxies! At the center of the Orion complex is the Orion nebula — and at its center a cluster of newly born stars. Photograph by Howard McCallon.

Text *continued from page 21*

across and, in many cases, are smeared and stretched out along the plane of the Milky Way.

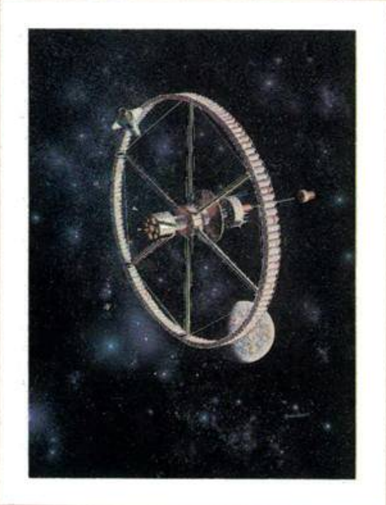
Studding the stellar background are the bright lights of star clusters. Our galaxy may contain 15,000 of these loose aggregates embedded in the disk and spiral arms. Some are ancient — nearly as old as the galaxy — and others are younger than a

Left: The Coalsack is justly renowned as the most impressive dark nebula. Four degrees across and 500 light-years away, the Coalsack is not so notable for its size (some 30 light-years diameter) as for its splendid isolation! Starlight passing through the Coalsack loses about two magnitudes. Photograph by Ronald Royer. Above: The Milky Way between Scutum and Cygnus is divided by the Great Rift, a complex interconnected string of absorbing clouds that hug the galactic plane. Photograph by Richard Berry.

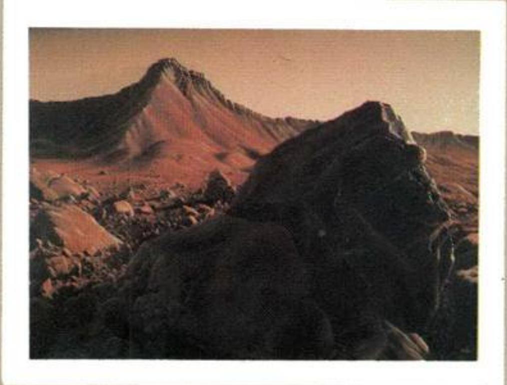
million years. Especially near the young clusters lie vivid emission nebulae, vast luminous clouds of gas. The gas, perhaps leftover from formation of the cluster, heats as the intense light of young stars excites the electrons of the atoms in the gas, and then glows as the electrons de-excite. A single extremely hot star can light up all the gas for hundreds of light-years — though such stars are rare — so sometimes a nebula may glow even though no stars sem to be embedded directly in it. Pushed by radiation, gas pressure and supernova explosions, and sheared by galactic rotation and magnetic fields, nebulous gas forms giant bubbles and streamers, arcs, and loops through space — almost a gaseous froth stirred by the star- making process in the galaxy.

So who's to say, the next time you contemplate the sky — whether through a telescope or via pictures published in a magazine — that you're wasting your time? How could you be, when there's so much to see?

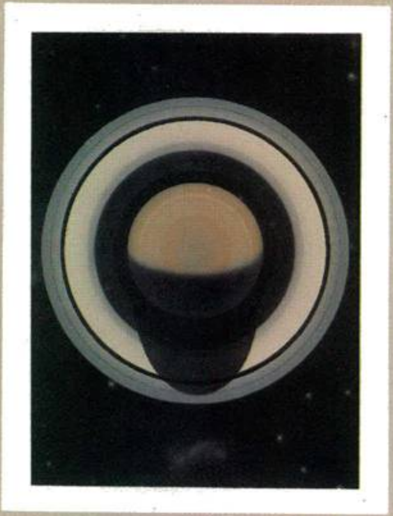
Colony in Space



Vallis Marineris



Saturn



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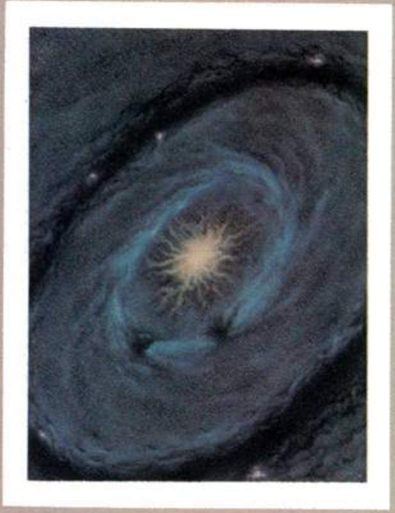

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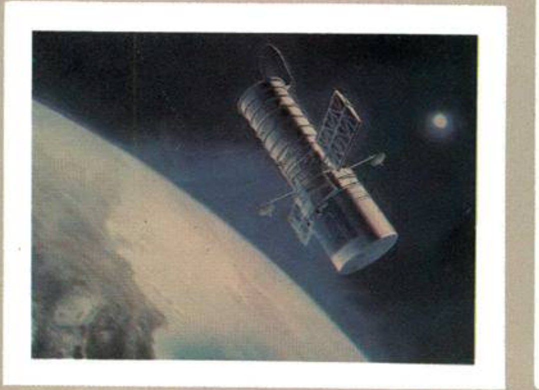
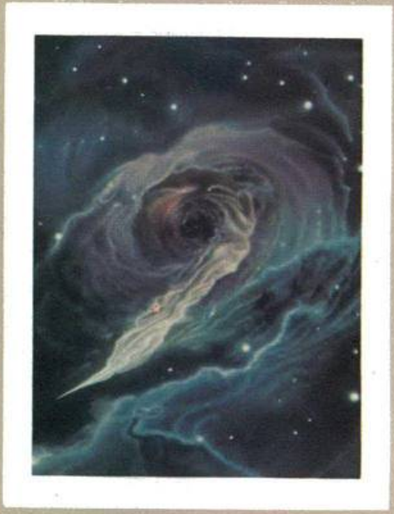


Black Hole



Colony in Space

What will space stations and orbiting colonies of the future look like? Artist Rick Sternbach provides an ingenious answer in his painting of a mile wide space station wheeling slowly above the gibbous Earth. Shuttle rockets near the station's hub bring ore from the lunar surface for refinement in the station's zero gravity manufacturing center.

The Galactic Core

The nucleus of our galaxy is one of the true unknowns in our universe. Recent radio and infrared observations suggest that two titanic swirling rings of gas and dust occupy the core of our galaxy. These rings were apparently produced by an explosion 10 million years ago. Victor Costanzo's painting indicates that actual conditions at the galaxy's center remain a mystery.

Vallis Marineris

Photographs returned from Mariner and Viking probes revealed for the first time the immensity of Vallis Marineris, the equatorial canyon of Mars. This painting by Adolf Schaller – meticulously transcribed from overhead Viking photos – takes us to the foot of a blanket of landslide rubble in the canyon itself.

Space Telescope

Painted by John Clark from official NASA blueprints, this poster depicts the Space Telescope – a powerful 94 inch (2.4 meter) aperture telescope due to be launched during the early 1980s by NASA's Space Shuttle. This is an accurate depiction of an instrument that will revolutionize man's view of the universe during the decades it remains in operation.

Saturn

In an unusual perspective from above the north pole of Saturn, we can identify the planet's three main rings and their sizes relative to Saturn itself, enabling us to grasp the vast extent of Saturn's ring system. This remarkable painting by Adolf Schaller gives us a view of the planet not obtainable from Earth.

Black Hole

A nearly invisible small black hole speeds through a dense interstellar cloud of gas and dust, leaving behind a trail of gravitationally disturbed material. The infalling material becomes hot and emits light as it drains out of the known universe. Artist Mark Paternostro speculates on the appearance of these still undetected objects.

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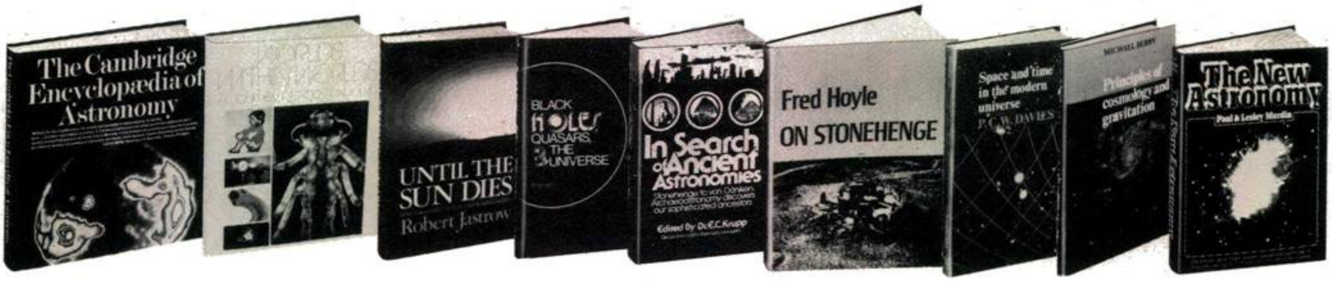
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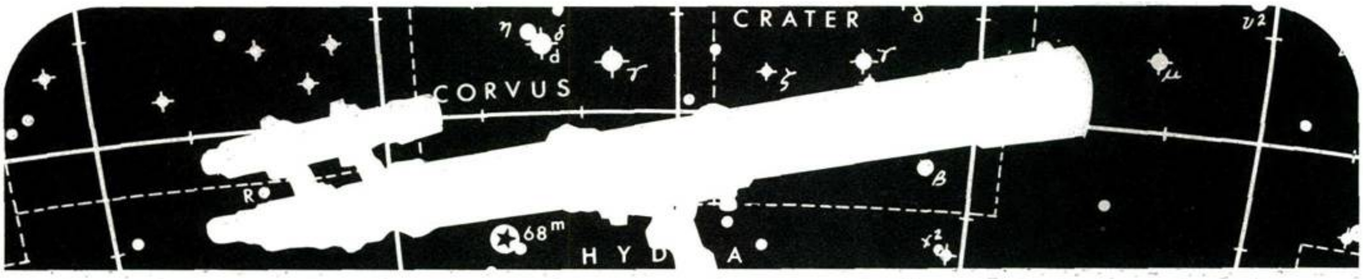


EQUIPMENT ATLAS

Celestial Software Part 3: Altitude and Azimuth

by
Richard Berry

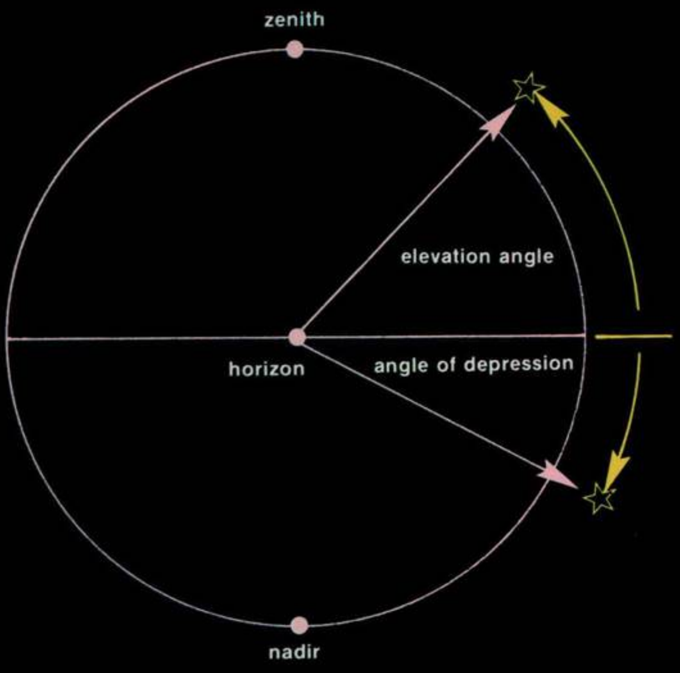
"Look around you...up and down...left to right...." You're already used to the horizon coordinate system, and you unconsciously use it every day. The horizon coordinate system is found in astronomy too, and in a somewhat fancier fashion, it's used in navigation, surveying and other practical areas. "But what is it?" you ask. "It sounds awfully dull!"

The horizon coordinate system is the most egocentric way of describing where things are. Coordinates in other systems — latitude, longitude, right ascension and declination — are tied to Earth, the spin of Earth and Earth's motion around the sun. But the horizon system is centered right on *you*. You stand at the center of your own horizon system of coordinates; it's all yours! All that's needed (in addition to yourself) to define a complete system — so you can point out anything that you can see — is two reference points. Although they could be anything you choose, the two most useful are the direction of the center of Earth and the direction of the north pole.

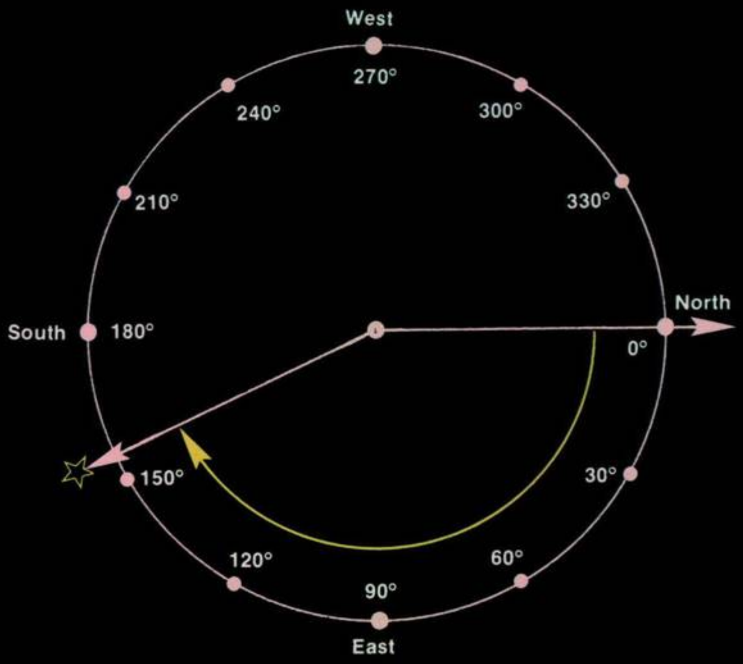
The center of Earth is "down", easily defined by hanging a weight from a string. You can find north with a compass (we'll come back to this later in more detail). Your personal coordinate system is thus completely defined with you in the middle of everything, and two handy reference directions you can easily find. If you walk around, you carry the coordinate system with you.

Let's look at the nomenclature of the horizon coordinates: First, why is it called the "horizon" system when all that's needed to define it is "down" and "north"? For a moment, let's think about what the horizon is. On Earth — at least at sea — the horizon is the place where the water and sky meet. Above is the dome of the sky; below is the flatness of the ocean. The horizon divides the observable world neatly in two: It encircles you. You are central, and "down" is precisely perpendicular to the horizon everywhere.

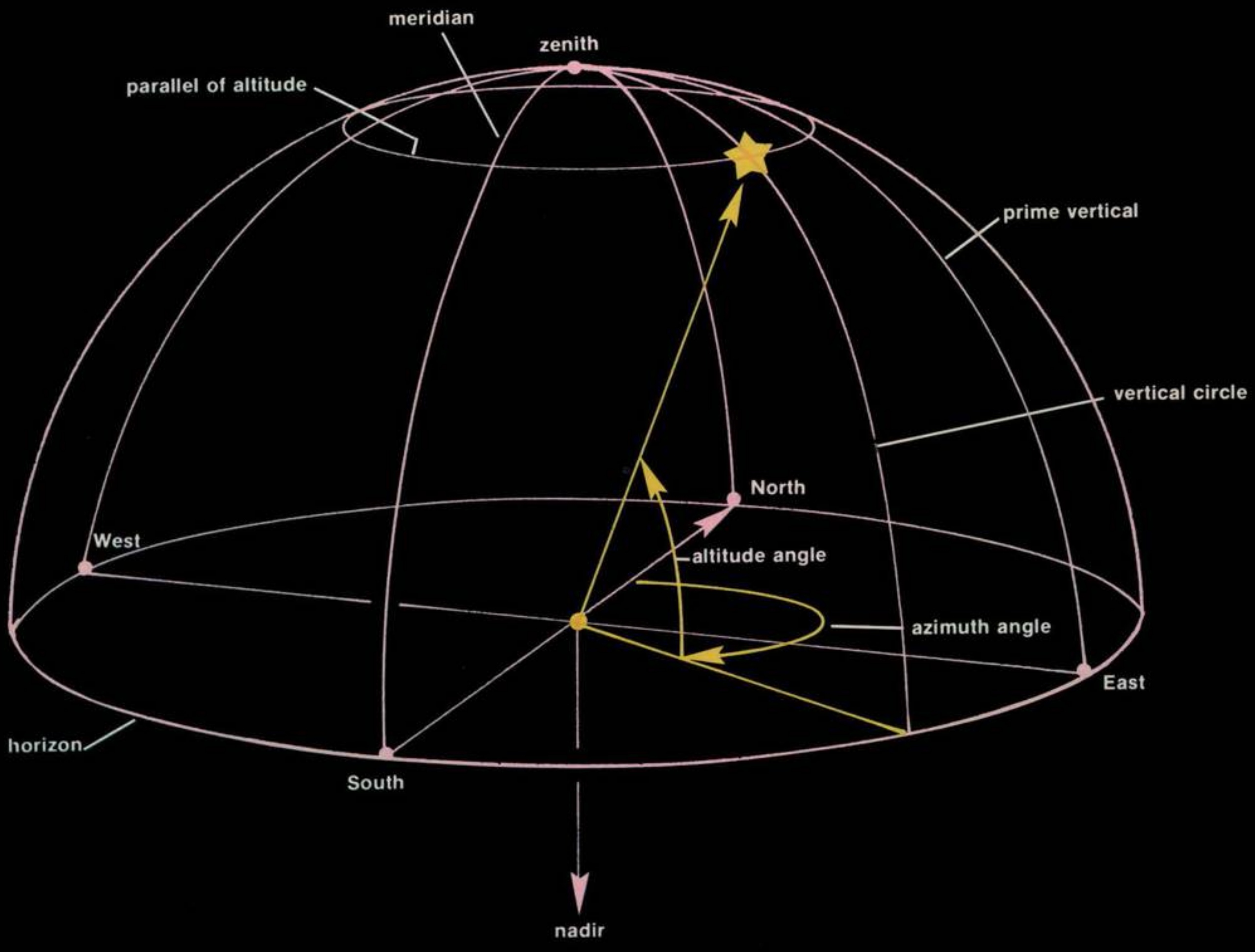
If you hang a plumb bob to define "down", and then use a carpenter's square to measure a right angle from the string, the other leg of the square will always point at the horizon. Thus the horizon is equivalent to "down" as a reference. You can — if it


zenith
elevation angle
horizon
angle of depression
nadir

ALTITUDE


West
270°
240°
300°
210°
330°
South
180°
North
0°
150°
30°
120°
60°
90°
East

AZIMUTH


meridian
zenith
parallel of altitude
prime vertical
vertical circle
North
West
altitude angle
azimuth angle
East
horizon
South
nadir

happens to be easier — define your coordinates in terms of the horizon. Since sailors always had the horizon available to them, and since the weight-on-a-string method doesn't work too well on a ship — it swings too much — sailors and navigators came to know the system as the *horizon coordinate system*.

The "down" direction is called the *nadir* (NAY-der), and the opposite, "up", is called the *zenith* (ZEE-nith). The horizon is perpendicular to both nadir and zenith which are, in turn, 180 degrees apart. If you measure the angle upward between the horizon and an object in the sky, the angle is called the *elevation angle* or *altitude*. If you measure the angle down to something below you — as you might from the top of the Eiffel Tower — the angle is called the *depression angle*. You can, for example, say: "Ah-ha, I see Venus at an altitude of 18 degrees" — meaning, of course, that Venus is 18 degrees above the horizon. If you stood on the rim of the Grand Canyon and exclaimed: "There's a mule train at a depression angle of 36 degrees," then you'd be looking down rather steeply.

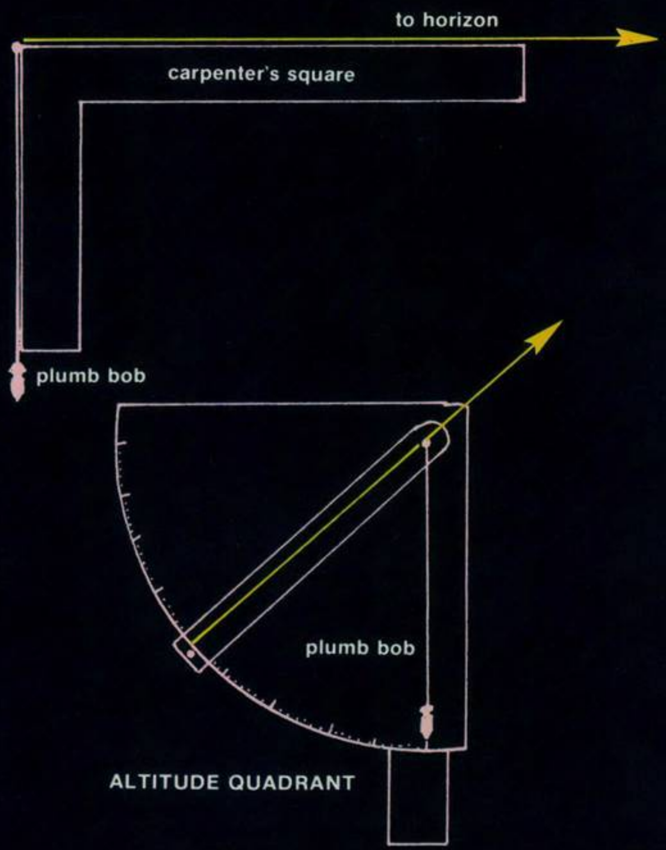
You may also encounter another angle called the *zenith distance*, which is the angle from the zenith to the object. Thus, for the examples above, Venus would have a zenith distance of 90 degrees minus 18 degrees or 72 degrees, while the mule train would have a zenith distance of 90 degrees plus 36 degrees, or 126 degrees. The nadir always has a zenith distance of 180 degrees, and the horizon (everywhere) has a zenith distance of 90 degrees.

Let's assume you happen to know where true north is. If you call the north point on the horizon 0 degrees, and then count off degrees measuring to the east — through the south, to the west and back to north — you'll count 360 degrees, or one complete turn. North, east, south and west are called the *cardinal points*, and are often assigned *azimuth angles* as follows:

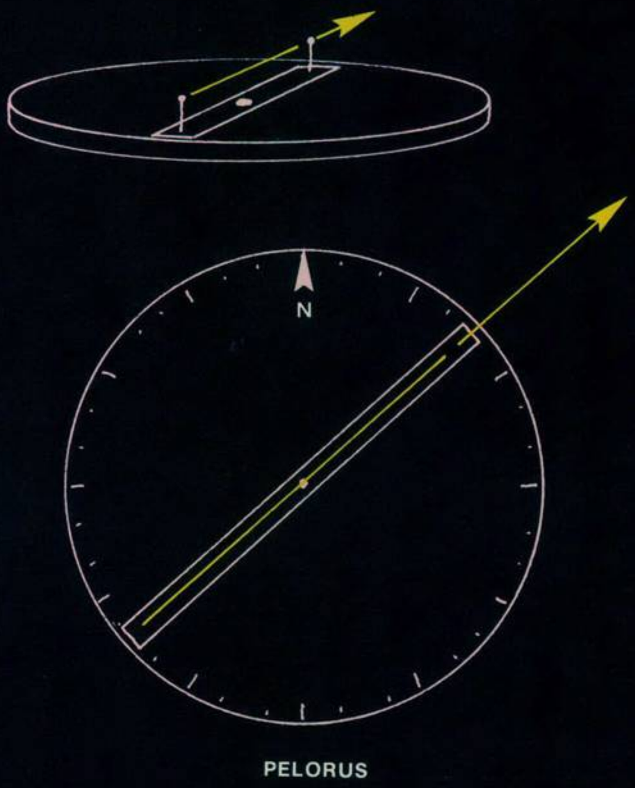
north	0°
east	90°
south	180°
west	270°

Unfortunately, you'll also find another system sometimes in use. In it, south is called 0 degrees, and angles are counted either east or west up to 180 degrees. It's definitely confusing! A point in the northwest may alternately be said to have an azimuth of 315 degrees, or to be 135 degrees west of south. Whenever possible, we'll stick to the simple 360 degree azimuth angle system.

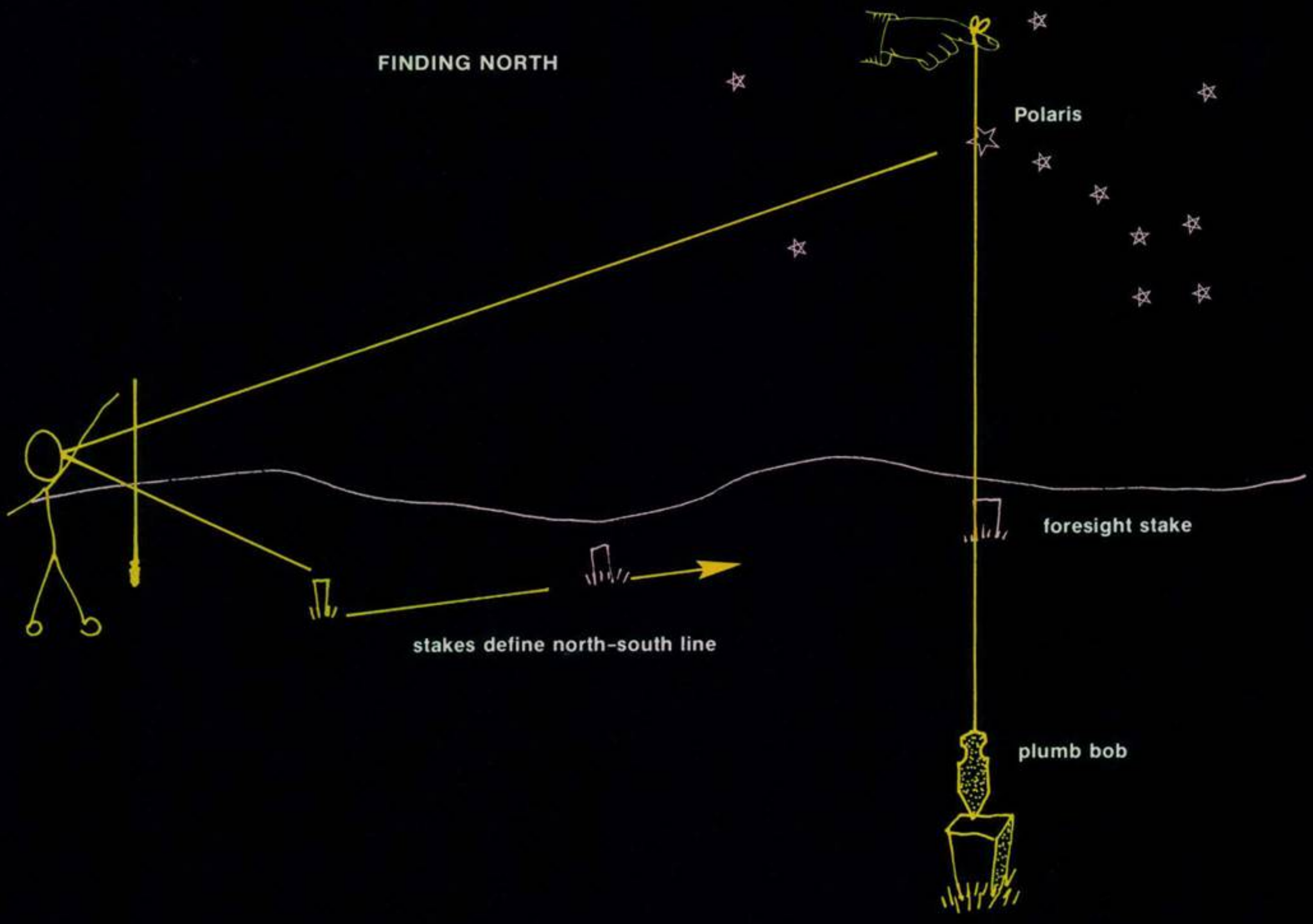
With a gadget called a *pelorus* (essentially a big protractor with sights), sailors measured angles to various other ships and nautical objects of interest. You can measure azimuth angles readily with a similar homemade device or a Boy Scout compass,



ALTITUDE QUADRANT



PELORUS



providing you can find the direction of north accurately to line up the numbered dial. (We'll come back to finding north later.)

You've certainly seen dramatic scenes in movies when the captain of a ship, plane, submarine or other vehicle calls to the engine room, or whatever, that he wants a new course of "two-nyun-faw". The brave captain is referring, of course, to the azimuth of the ship's course. They use three digits — 090 for due east — in order to minimize errors. The degree sign is omitted so it can't be confused with a zero. Besides, it sounds good: "Roger, cap'm', course too-nahn-foe!" The result is that the ship swings round until it's sailing some 24 degrees north of west, at an azimuth of 294 degrees, either toward or away from danger.

An object well above the horizon has the same azimuth as an object directly below it on the horizon. The line (imaginary, of course) running from the horizon through the object to the zenith is called a *vertical circle* . Every point on a vertical circle has the same azimuth, though each has a different altitude. The *meridian* is a vertical circle with an azimuth of 180 degrees, or due south. When the sun is on the meridian, it is due south; it has reached its highest point for the day, and the time is solar noon. The meridian continues across the sky to the north, with an azimuth of 0 degrees. Normally no distinction is made between the north and south meridian. East and west vertical circles get a special name also: They are the *prime verticals*. The meridian and prime verticals intersect at the zenith as, in fact, all vertical circles meet at the zenith.

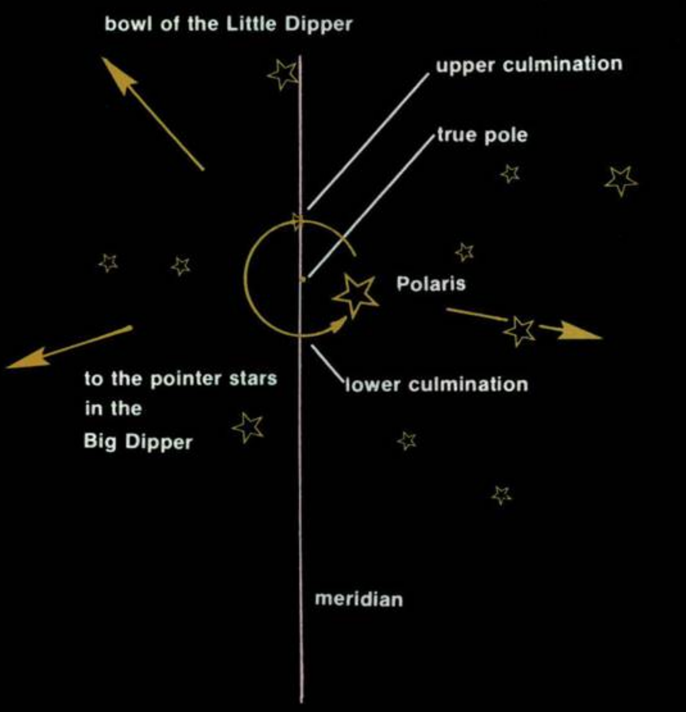
Running parallel to the horizon at various altitudes around the sky are *parallels of altitude*. All stars 60 degrees above the horizon, for example, lie on the same parallel altitude. To look for an object that you happen to know has an altitude of 25 degrees (but you don't know the azimuth), you'd search along the parallel of altitude.

The link between the horizon coordinate system — which is centered on you — and the system of right ascension and declination — which is centered on Earth's center — is your use of the nadir and north point as your references. The nadir is the direction of Earth's center; the north point is the direction of Earth's pole. Thus the horizon system and the celestial sphere are inextricably joined. Also linked is your position on Earth, as defined by longitude and latitude. You lie a certain angular distance from Earth's pole, and some certain angular distance from the zero point of the longitude system.

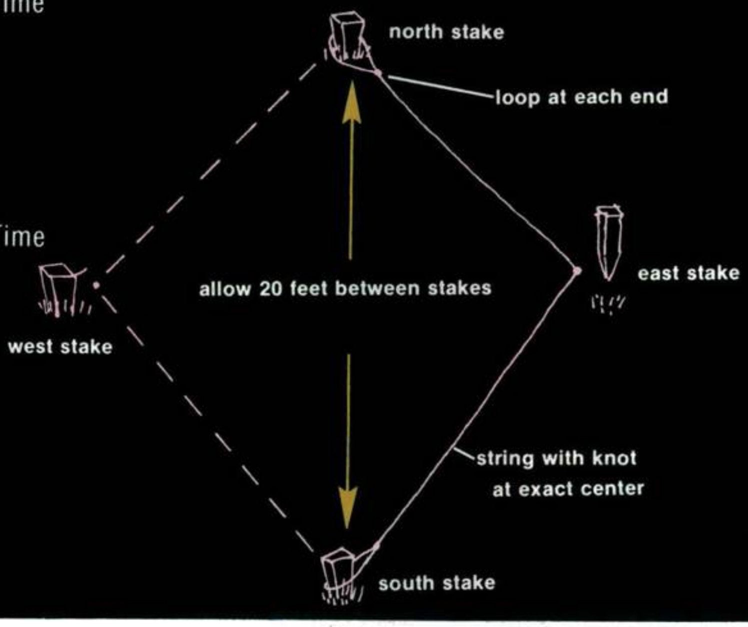
You also occupy a changing point in time that ties your position on Earth, Earth's rotation and the position of objects in the sky together. You can, for example, find what the altitude and azimuth of any star will be if you know the date and time, your

Upper and Lower Culminations of Polaris

		Upper	Lower	
Jan.	7	7 p.m.	7 a.m.	
Jan.	21	6 p.m.	6 a.m.	
Feb.	7	5 p.m.	5 a.m.	Standard Time
Feb.	21		4 a.m.	
Mar.	7		3 a.m.	
Mar.	21		2 a.m.	
Apr.	7		1 a.m.	
Apr.	21		12 p.m.	
May	7		12 p.m.	
May	21		11 p.m.	
June	7		10 p.m.	
June	21		9 p.m.	
July	7	Daylight Interferes		
July	21			Daylight Time
Aug.	7	6 a.m.		
Aug.	21	5 a.m.		
Sept.	7	4 a.m.		
Sept.	21	3 a.m.		
Oct.	7	2 a.m.		
Oct.	21	1 a.m.		
Nov.	7	11 p.m.		
Nov.	21	10 p.m.		Standard Time
Dec.	7	9 p.m.		
Dec.	21	8 p.m.		


bowl of the Little Dipper
upper culmination
true pole
Polaris
to the pointer stars in the Big Dipper
lower culmination
meridian

FINDING THE EAST-WEST LINE


north stake
loop at each end
east stake
allow 20 feet between stakes
west stake
string with knot at exact center
south stake

longitude and latitude, and the position of that star on the celestial sphere. Conversely, through the wonders of spherical trigonometry, navigators can find their longitude and latitude from a sighting and measurement of the altitude and azimuth of a star. Though it may seem a bit forbidding, modern pocket calculators remove most of the drugery from the math.

The horizon coordinate system provides a practical way to describe where you see stars and planets in the sky, so we'll get down to the real nitty-gritty of defining your coordinate system and using it. Without even looking, you can easily find one of your reference points. Make a nadir/zenith line with a freely hanging string with a weight on the end. Carpenter's plumb bobs (available in hardware stores) that are pointed on the bottom are best. These are easy to align exactly over a mark or nail — which isn't easy if you weight your string with a rock! The horizon lies at right angles to the string. You can sight on the horizon if you hang a small weight on a thread attached to a carpenter's square (see drawing). Go a step further and attach the reference plumb directly to a protractor dial. Such an instrument — which you can build yourself — is called an *altitude quadrant.*

The other reference is north. It would be nice if a magnetic compass gave true north, but it doesn't. The magnetic field of Earth is only crudely aligned with its rotation. Thus a compass pointing to *magnetic north* can err by many degrees from true north. You can find true north, however, by sighting on the stars; in particular, you can sight on Polaris, the north star. Polaris — unfortunately — is not exactly true north; it travels in a circle about one degree in radius around the pole. When Polaris crosses the meridian (which it does twice each day), it lies exactly on the vertical circle that passes through north. If you don't mind an error of a degree or so, Polaris is an adequate reference. If you need greater accuracy, refer to the table on page for the times of upper and lower culminations of Polaris — those times when Polaris lies above or below the true pole.

Now you can play surveyor by finding a true north-south line on Earth's surface. Pound a stake into the ground in a place where the pole star is visible — preferably an open grassy field. At the time of either of the culminations of Polaris, hold a weighted thread or plumb line at arm's length and walk around any distance south of the stake until the thread passes through Polaris and the stake simultaneously. Pound in another stake at that spot (here's where a carpenter's bob is especially handy!). The line between the two stakes is a true north-south line. To check the line, step back and make sure that the thread passes through both stakes and Polaris simultaneously.

There are lots of variations on this basic method. You can hang a plumb bob at the corner of a house (take care that it doesn't touch the wall anywhere), and then step back to place a marker where Polaris lines up with the string. Another marker under the bob defines a north-south line. If you need to know the direction of the east-west line, you can use the simple string method (shown in the diagram on page 38) to place stakes in the ground or paint marks on paved surfaces. If you work carefully, you can probably determine the directions to the cardinal points within a few minutes of arc — and certainly to better than 1/10 degree.

You needn't use Polaris, of course. Any star that's on the meridian, including the sun, is sufficient to find the north-south line. However, because Polaris is close to the pole, small errors in finding the exact time of transit become unimportant.

Once you've defined a line pointing true north, you can measure the azimuth of any object with a protractorlike pelorus or compass card. Align the 0 degree mark with the north-south line and then read out azimuths directly.

You'll enjoy being in the center of things when you use the horizon coordinate system. Not only will you know precisely where the cardinal points are, but you'll be able to find elusive sky objects like Mercury more easily. Most important, though, you'll find that understanding altitude and azimuth will add to your familiarity with the sky — and your place, as the center of your own coordinate system.

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First in its Class
The Meade 6" Model 591:

A High-Performance Lunar, Planetary, and Deep-Space Instrument for Visual or Photographic Applications.

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Complete: **$279 50**

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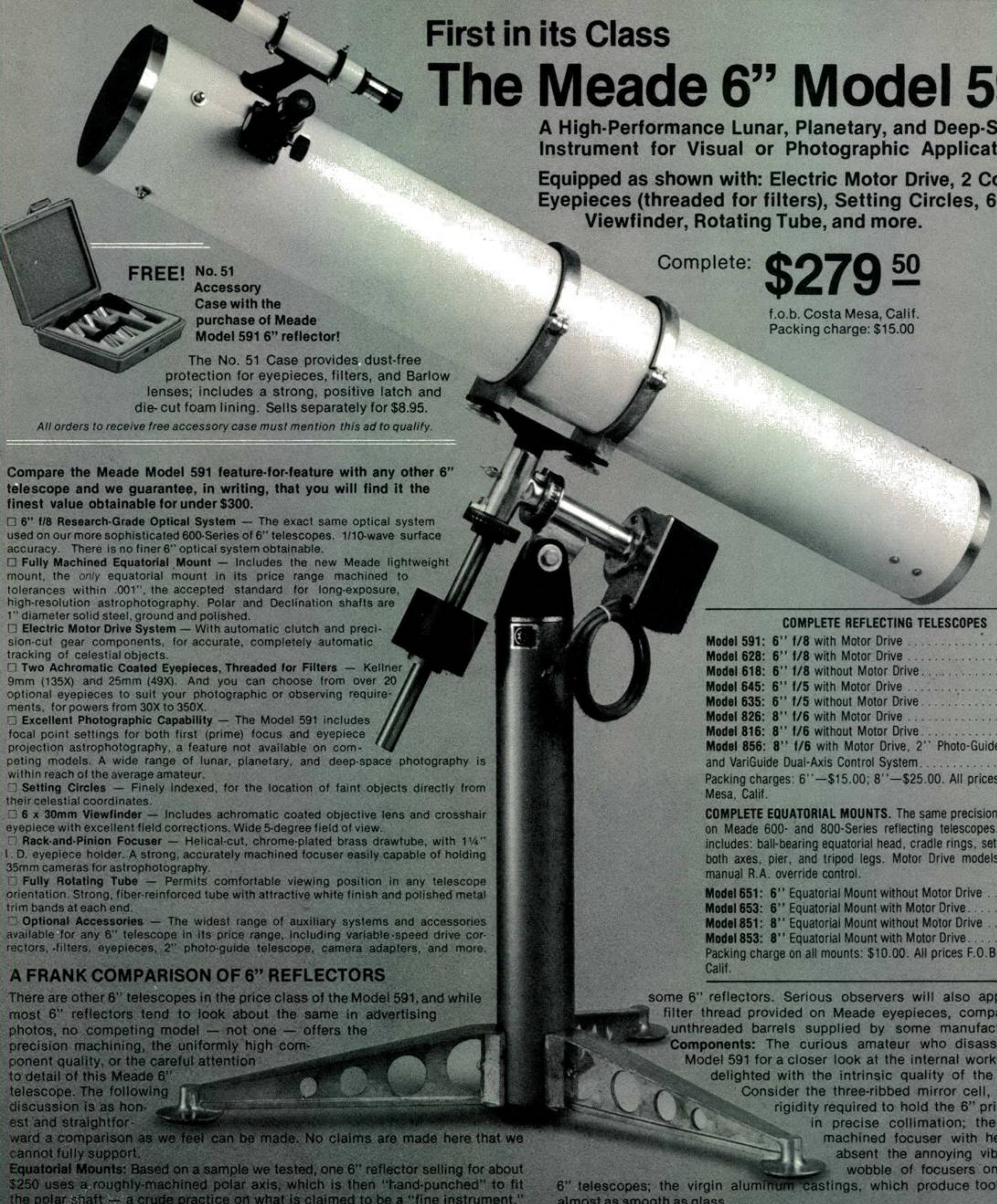


FREE! No. 51 Accessory Case with the purchase of Meade Model 591 6" reflector!

The No. 51 Case provides dust-free protection for eyepieces, filters, and Barlow lenses; includes a strong, positive latch and die-cut foam lining. Sells separately for $8.95.

All orders to receive free accessory case must mention this ad to qualify.

Compare the Meade Model 591 feature-for-feature with any other 6" telescope and we guarantee, in writing, that you will find it the finest value obtainable for under $300.

☐ **6" f/8 Research-Grade Optical System** — The exact same optical system used on our more sophisticated 600-Series of 6" telescopes. 1/10-wave surface accuracy. There is no finer 6" optical system obtainable.

☐ **Fully Machined Equatorial Mount** — Includes the new Meade lightweight mount, the *only* equatorial mount in its price range machined to tolerances within .001", the accepted standard for long-exposure, high-resolution astrophotography. Polar and Declination shafts are 1" diameter solid steel, ground and polished.

☐ **Electric Motor Drive System** — With automatic clutch and precision-cut gear components, for accurate, completely automatic tracking of celestial objects.

☐ **Two Achromatic Coated Eyepieces, Threaded for Filters** — Kellner 9mm (135X) and 25mm (49X). And you can choose from over 20 optional eyepieces to suit your photographic or observing requirements, for powers from 30X to 350X.

☐ **Excellent Photographic Capability** — The Model 591 includes focal point settings for both first (prime) focus and eyepiece projection astrophotography, a feature not available on competing models. A wide range of lunar, planetary, and deep-space photography is within reach of the average amateur.

☐ **Setting Circles** — Finely indexed, for the location of faint objects directly from their celestial coordinates.

☐ **6 x 30mm Viewfinder** — Includes achromatic coated objective lens and crosshair eyepiece with excellent field corrections. Wide 5-degree field of view.

☐ **Rack-and-Pinion Focuser** — Helical-cut, chrome-plated brass drawtube, with 1¼" I. D. eyepiece holder. A strong, accurately machined focuser easily capable of holding 35mm cameras for astrophotography.

☐ **Fully Rotating Tube** — Permits comfortable viewing position in any telescope orientation. Strong, fiber-reinforced tube with attractive white finish and polished metal trim bands at each end.

☐ **Optional Accessories** — The widest range of auxiliary systems and accessories available for any 6" telescope in its price range, including variable-speed drive correctors, filters, eyepieces, 2" photo-guide telescope, camera adapters, and more.

A FRANK COMPARISON OF 6" REFLECTORS

There are other 6" telescopes in the price class of the Model 591, and while most 6" reflectors tend to look about the same in advertising photos, no competing model — not one — offers the precision machining, the uniformly high component quality, or the careful attention to detail of this Meade 6" telescope. The following discussion is as honest and straightforward a comparison as we feel can be made. No claims are made here that we cannot fully support.

Equatorial Mounts: Based on a sample we tested, one 6" reflector selling for about $250 uses a roughly-machined polar axis, which is then "hand-punched" to fit the polar shaft — a crude practice on what is claimed to be a "fine instrument." The declination shaft of the same telescope wobbles in its casting unless literally locked in place. Meade equatorial mounts are fully machined on $10,000 lathes to tolerances within .001", and are capable of the fine guiding absolutely essential for serious observing and quality astrophotography.

Eyepieces: The Kellner eyepieces supplied with the Model 591 yield apparent fields of view significantly wider than the Ramsden eyepieces supplied with some 6" reflectors. Serious observers will also appreciate the filter thread provided on Meade eyepieces, compared to the unthreaded barrels supplied by some manufacturers.

Components: The curious amateur who disassembles his Model 591 for a closer look at the internal workings will be delighted with the intrinsic quality of the instrument. Consider the three-ribbed mirror cell, with all the rigidity required to hold the 6" primary mirror in precise collimation; the beautifully machined focuser with helical gears, absent the annoying vibrations and wobble of focusers on competing 6" telescopes; the virgin aluminum castings, which produce tooled surfaces almost as smooth as glass.

In sum, if we seem to be proud of our 6" telescope, it's because we know the Model 591 is the best in its class by a wide, wide margin.

And we guarantee you will agree.

COMPLETE REFLECTING TELESCOPES

Model 591: **6" f/8** with Motor Drive	$279.50
Model 628: **6" f/8** with Motor Drive	379.95
Model 618: **6" f/8** without Motor Drive	339.95
Model 645: **6" f/5** with Motor Drive	389.95
Model 635: **6" f/5** without Motor Drive	349.95
Model 826: **8" f/6** with Motor Drive	489.95
Model 816: **8" f/6** without Motor Drive	429.95
Model 856: **8" f/6** with Motor Drive, 2" Photo-Guide Telescope, and VariGuide Dual-Axis Control System	770.00

Packing charges: 6"—$15.00; 8"—$25.00. All prices F.O.B. Costa Mesa, Calif.

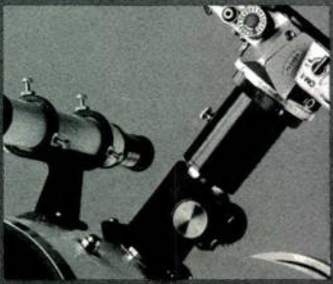
COMPLETE EQUATORIAL MOUNTS. The same precision mounts used on Meade 600- and 800-Series reflecting telescopes. Each mount includes: ball-bearing equatorial head, cradle rings, setting circles on both axes, pier, and tripod legs. Motor Drive models also include manual R.A. override control.

Model 651: **6"** Equatorial Mount without Motor Drive	$140.00
Model 653: **6"** Equatorial Mount with Motor Drive	195.00
Model 851: **8"** Equatorial Mount without Motor Drive	165.00
Model 853: **8"** Equatorial Mount with Motor Drive	225.00

Packing charge on all mounts: $10.00. All prices F.O.B. Costa Mesa, Calif.

GUARANTEE

The Meade Model 591 is guaranteed to be the finest telescope—*in every detail*—of any 6" reflector in its price class. The purchaser of the Model 591 may return the telescope to us within 10 days of receipt, in its original condition and freight prepaid, for a full and immediate refund, if not completely satisfied with the instrument. This guarantee is valid whether the telescope is purchased by mail order, telephone order, or in our Costa Mesa showroom.



Research level telescope parts and accessories from America's No. 1 supplier to the serious amateur

1 - Series 1 KELLNER EYEPIECES (1¼" O.D.) — Highly corrected, 3-element design, fully coated. The best in moderately priced eyepieces. Barrels threaded for our filters. **Focal lengths: 6, 9, 12, 25mm . . . each $14.50 ppd. — 40mm Wide-Field . . . $16.50 ppd.**

2 - KELLNER 40mm EXTRA-WIDE-FIELD EYEPIECE (1¼" O.D.) — Yields widest field obtainable in 1¼" O.D. Enlarged field lens and special field-flattening optics with long eye relief. Barrel accepts our filters. **$24.75 ppd.**

3 - Series 1 ORTHOSCOPIC EYEPIECES (1¼" or .965" O.D.) — Our most popular eyepieces, over 25,000 now in use. Classical 4-element design, 45° field, fully coated, with precise corrections for color and field flatness. All 1¼" barrels are threaded for our filters. **Focal lengths: 4, 6, 9, 12.5, 18, 25mm . . . each $23.75 ppd.**

4 - Research-Grade ORTHOSCOPIC EYEPIECES with Multi-Coated, Parfocal Optics (1¼" O.D.) — The largest-selling premium-quality eyepieces in the world, universally acclaimed to be the finest oculars obtainable. These 4-element systems are unsurpassed in resolution, color correction, and flatness of field. Air-to-glass surfaces are 7-layer multi-coated for maximum image contrast and light transmission. 45° field. Precisely parfocal. Barrels threaded for our filters.

Focal lengths: 4, 7, 10.5, 16.8, 28mm . . . . each $38.95 ppd.
Set of any 4 Research-Grade Orthoscopics . . . . 151.00 ppd.
Set of any 4 plus Res. Grade Erfle 20mm. . . . . 193.00 ppd.
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plus Erfle 20mm . . . . 229.50 ppd.
(Sets of 4, 5, or 6 eyepieces are shipped in fitted carrying case — see #25 — at no additional charge.)

5 - Research-Grade ERFLE 20mm (1¼" O.D.) — Parfocalized with our Research-Grade Orthoscopics and 7-layer multi-coated. 75° apparent field for breathtaking wide-angle observations. Barrel accepts our filters. **$44.50 ppd.**

6 - Zoom Kellner Eyepiece (.965" O.D.) — Fine 4-element design. Zoom range 7.5mm - 22.5mm. Fully coated optics . . . **$32.95 ppd.**

7 - Zoom Orthoscopic Eyepiece (1¼" O.D.) — Zooms instantly from 8.4mm to 21mm, with excellent image corrections at all powers. Wide 50° field at 8.4mm. Fully coated optics. **$49.95 ppd** - Filter adapter #004: couples our filters to above eyepiece . . . **$1.00 ppd.**

8 - Photo-Visual Color Filters - Top quality optical glass, dyed-in-the-mass, with excellent spectral homogeneity. Mounted in machined metal cells which thread directly into all our 1¼" "Series1" and "Research-Grade" eyepieces. Filters may be piggybacked. Listed by Wratten No. and color: **#8 Light Yellow - #11 Yellow-Green - #12 Yellow - #21 Orange - #23A Light Red - #25A Red - #47 Violet - #58 Green - #80A Medium Blue - Polarizer (30% transmission).** Each filter: **$6.95 ppd.** Set of any 6: **$39.50 ppd.** - Full set of 10: **$64.50 ppd.**

9 - VariPak Drive Corrector — This low-cost quality unit includes all the features required for the majority of guiding applications. New super-compact (2" x 3" x 4") design, with fast-slow pushbuttons mounted on the power pack. Variable control for lunar, planetary, sidereal rates. Operates from 12 volts D.C. The 8 watt output is sufficient for most telescopes to 10" aperture. **$59.95 ppd.**

10 - VariGuide Drive Correctors — The finest R.A. drive correctors available. Each unit includes aircraft-type joystick controller for continuously variable correction rates, not just "ON-OFF". Models 40 and 41 may be used with any motor-drive-equipped telescope rated up to 10 watts, including most commercial telescopes to 12½" aperture.
Model 40 — Operates from 12 volts D.C. Control box includes variable center-frequency settings for lunar, planetary, sidereal rates. **$89.95 ppd.**
Model 41 — Identical to Model 40, but operates from either 12 volts D.C. or 115 volts A.C./60Hz. **$119.95 ppd.**

11 - VariGuide Dual-Axis Corrector Systems — For the advanced astrophotographer. Universal joystick controllers permit continuously variable correction rates **simultaneously** on **both** telescope axes. Each unit includes electronic control systems for both R.A. and Declination, along with all required mounting hardware. Models are available to fit Meade 600- and 800-Series reflectors and for the Celestron 5 and 8, as noted. After 15 minutes' installation, you will be using the most sophisticated and precise guiding system ever offered the serious amateur.
Model 47M — Attaches to Meade 600- and 800-Series reflectors. Operates from either 12 volts D.C. or 115 volts A.C./60Hz. **$215.00 ppd.**
Model 47C — Attaches directly to Celestron 5" and 8" telescopes. Operates from either 12 volts D.C. or 115 volts A.C./60Hz. **$195.00 ppd.**

RACK-AND-PINION FOCUSERS — Precision metal construction. All 3 models include helical-cut rack and variable-tension adjustment for ultra-smooth focusing without backlash. Universal bases fit all tube sizes. Standard 1¼" eyepiece holders. **Each focuser is guaranteed to be the finest obtainable in its class.**

12 - Model #67 — Strong, lightweight design for 4" to 10" telescopes. 2-3/16" travel. An excellent value. **$19.75 ppd.**

13 - Model 640 — A heavy-duty deluxe focuser for 6" to 16" telescopes. Full 3" travel for both visual and photographic applications. **$33.95 ppd.**

14 - Model 680 — Our finest focuser. Accepts both 1¼" and 2" eyepieces. Full 3" travel for photo or visual observing with 6" to 16" telescopes. **$39.95 ppd.**

15 - Deluxe Camera Adapters — Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum. All units permit both eyepiece-projection and first (prime) focus photography. Specify either .965" or 1¼" focuser. All 1¼" units are threaded for our filters. Pentax, Yashica, Mamiya . . . **$18.95 ppd.** - Nikon, Canon, Minolta, Pentax K, Exakta, Konica . . . **$27.95 ppd.** - Olympus OM-1, OM-2 . . . **$28.95 ppd.**

16 - 2" First (Prime) Focus Adapter — For use with #680 Focuser or equivalent. Yields widest photographic field obtainable with 35mm cameras. For any of the above-listed camera brands (specify brand) . . . **$27.50 ppd.**

VIEWFINDERS — Each finder includes coated, achromatic objective lens and crosshair eyepiece.

17 - 6 x 30mm — Fine, 4° wide-field finder. Thousands now in use. 2-ring bracket included, fits all tubes 6" to 12½". **$21.95 ppd.**

18 - 6 x 30mm Right-Angle — As in (17), but with diagonal prism for convenient right-angle observations. Bracket included. **$27.95 ppd.**

19 - 8 x 50mm — 5° field and large 50mm aperture. Sharp, brilliant images. **$33.95 ppd.** Brackets: **$7.95/pr. ppd.**

20 - 8 x 50mm Right-Angle — As in (19), but with diagonal prism. For both straight-through and right-angle viewing. **$39.95 ppd.** Brackets: **$7.95/pr. ppd.**

2" O.D. SUPER-WIDE-FIELD EYEPIECES — Premium-quality wide-field eyepieces for 2" focusers. The ultimate in rich-field performance. Fully coated.

21 - ERFLE 32mm (2" O.D.) — Sophisticated 5-element optical system. Wide, flat 65° field . . . **$94.50 ppd.**
ERFLE 32mm (1¼" O.D.) — As above, but 1¼" O.D., 60° field . . . **$94.50 ppd.**

22 - KELLNER 60mm (2" O.D.) — Low power, long eye relief. Ideal for deep-space observations . . . **$49.50 ppd.**

23 — 2X and 3X TELENEGATIVE AMPLIFIERS (1¼" O.D.) — Warranted, without qualification, to be the world's finest Barlow lenses. Full 26mm clear aperture, with virtually flawless optical corrections at all photo-visual wavelengths. Produces optimum performance on telescopes of any focal ratio. Fully coated. **2X Model 122 . . . $29.50 ppd. - 3X Model 123 . . . $32.50 ppd. - Combination 2X and 3X Model 124 . . . $39.50 ppd.**

24 - Fiberlite telescope tubes, mirror cells, spiders, primary mirrors from 6" to 12½" diameter, secondary mirrors, and objective lenses are available for immediate shipment. (Phone, or request catalog, for details.)

ACCESSORY CASES — Rugged polyethylene, for dust-free protection of eyepieces, filters, Barlows, etc. Die-cut foam lining.

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27 - ILLUMINATED RETICLE GUIDING EYEPIECE (1¼" or .965" O.D.) — For professional-level photographic guiding. Kellner 12mm optical system, with precisely focusable 4-line glass reticle. Remote brightness control and 3 ft. cable. (Extension cables available.) Complete . . . **$44.95 ppd.**
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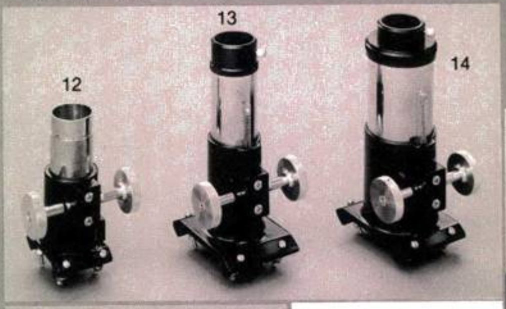

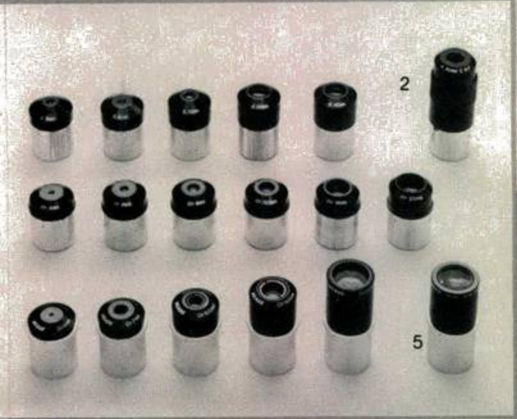

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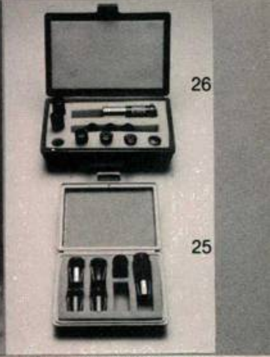

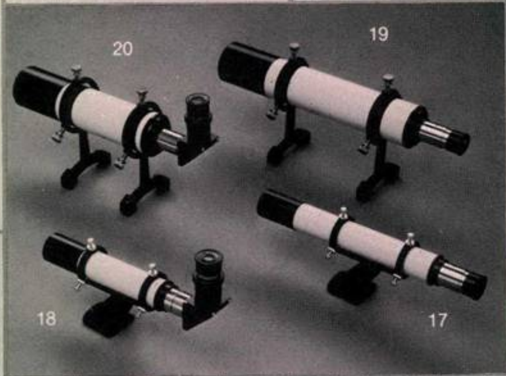

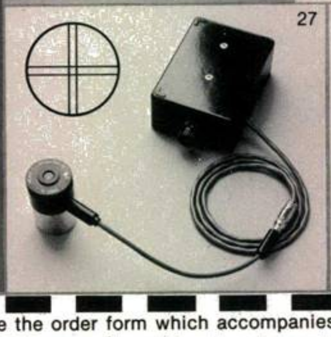

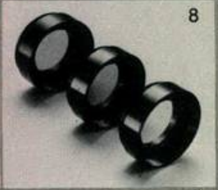

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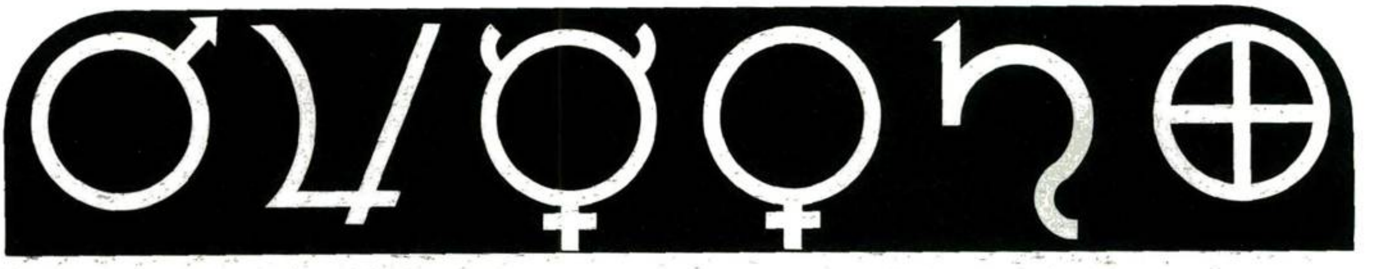


SKY ALMANAC

Mercuryshine in the Morning

by

Robert Burnham

Many people consider September to be the ideal month for sky watching. The constellations arrayed above are superb, and the slightly cooler nights aren't uncomfortable yet — just invigorating! Overhead the summer triangle (Vega, Altair and Deneb) is prominent, and the Milky Way crosses the sky from northeast to southwest.

For this particular September, there's a favorable elongation of Mercury, a bright appearance of Venus, and an occultation of Aldebaran by the moon. Jupiter is an ideal object in the early morning, accompanied by Saturn late in the month. All in all, there's a lot to be seen!

Mercury

This year's best elongation of Mercury in the morning sky will be in September, but you'll have to be up early to catch it. This elongation is 18 degrees west, meaning that Mercury will rise *ahead* of the sun. The illustration (see page 43) shows the altitude and azimuth where you'll find Mercury at sunrise between Aug. 31 and Sept. 26. Although the chart was computed for an observer at 40 degrees latitude, the variation won't be too much for the entire United States and southern Canada. (We're also including the azimuth of sunrise for the 1st and 26th.)

The planet's magnitude on the 4th, the date of greatest elongation, will be +0.1. Although Mercury will brighten dramatically during the following week, the decreasing separation from the sun will take back most of the magnitude gain.

On the 4th, the elevation above the horizon at sunrise will be about 16 to 17 degrees, but since the sun will make the sky very bright, you should start looking earlier in the morning. During the last few days of August and the first few of September, if you begin looking 45 to 60 minutes before sunrise, you'll stand a very good chance of seeing it. Binoculars are probably the best instrument to use. Remember that a low eastern horizon free of ground clutter is essential!

As the illustration shows, after about Sept. 18, you'll have a hard time spotting Mercury since the planet's elevation quickly drops. This is because the elongation is a "perihelic" one. Mercury goes through its point of closest approach to the sun (perihelion) on the 9th. At this point in its orbit, Mercury's moving very fast — almost 37 miles (60km) per second — which makes the day-to-day changes large. By the 30th, Mercury will have zipped around to superior conjunction!

Venus

As the month begins, Venus can be seen in the southwest at sunset, about 16 degrees above the horizon. If you watch carefully over the month, you'll notice an increase in brightness from magnitude -4.0 to -4.3. You won't see it get much brighter until the planet reappears in the morning sky during the last few weeks of this year.

In a telescope, its size will grow to almost 38 seconds of arc in diameter by Sept. 30, having started at 25 seconds on the 1st. Since it passed greatest elongation last month, Venus, now rapidly overtaking Earth, is heading for inferior conjunction. Even though the phase of the planet as seen in a telescope is becoming more and more a thin crescent, the visible magnitude grows because the planet is drawing nearer Earth.

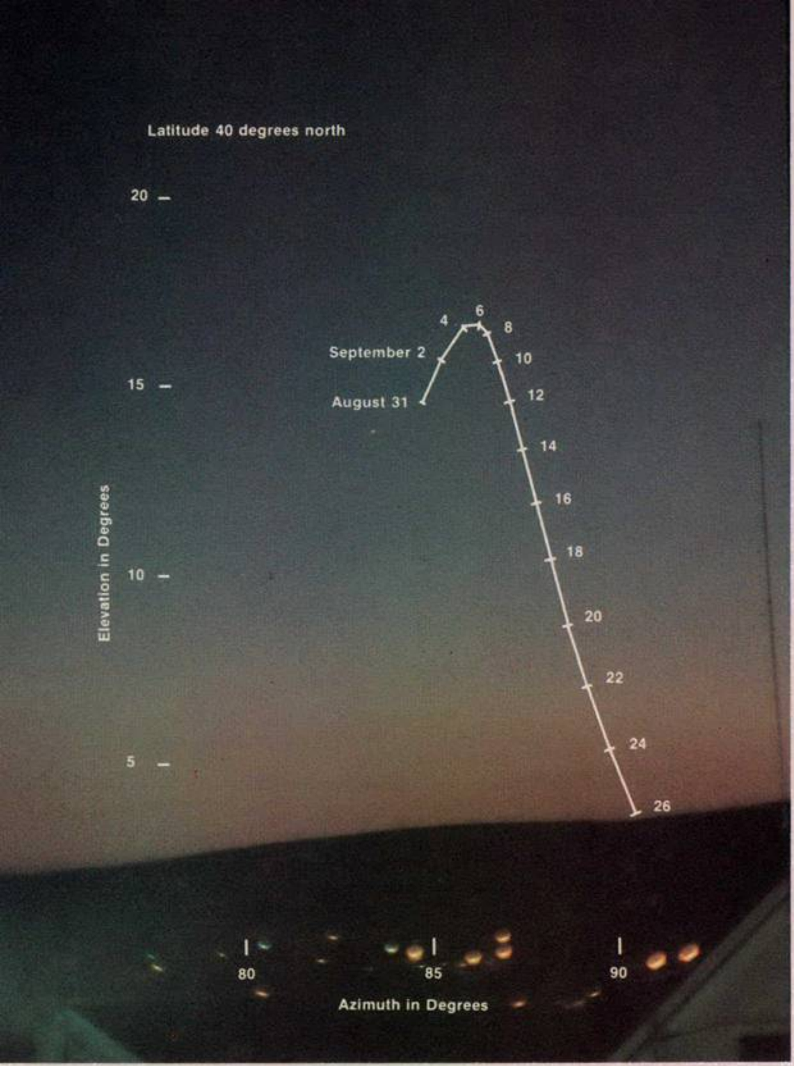
September is probably the last month (in this elongation) during which you'll be able to view Venus without difficulty. By the 30th, the elevation at sunset will be only 11 degrees. There's a lot of atmosphere to look through and you'll find the distortion and atmospheric color through your telescope's eyepiece very obtrusive.

Moon

Later this month a relatively rare event will happen which can be seen in most of the U. S. and southern Canada. On the morning of Sept. 22, a waning gibbous moon will occult (cover up) the first magnitude star Aldebaran (Alpha Tauri) in the Hyades cluster. Aldebaran is the brightest star the moon can occult.

The occultation happens around 7:00 a.m. daylight time for those living in the eastern time zone, 5:30 a.m. for the central time zone, 4:00 a.m. for the mountain zone, and 2:30 a.m. for the Pacific coast. Hawaiian observers will see it around midnight. These predictions are only general, so get set

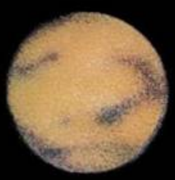
Top left: This illustration shows the path of Mercury as it approaches and passes its greatest western elongation point. The photograph used for the backdrop is a two second exposure on High Speed Ektachrome (pushed to ASA 400) taken with a 100mm lens at f/3.8. Photograph by William P. Duffy. Top right: On June 4, Mars passed 1/10 degree from Saturn, setting the stage for this magnificent shot taken at 9:45 p.m. EDT with a Celestron 14. The exposure was 1-1/2 seconds on High Speed Ektachrome. Photograph by Perry Walker. Bottom: Mars and Saturn nearly appear as one in this overall view of the constellation Leo. This is a 10 second exposure on Ektachrome film pushed to ASA 400, taken with a tripod mounted Fujica ST-801 and a 50mm lens at f/1.8. Photograph by James R. Westlake Jr.


Latitude 40 degrees north
Elevation in Degrees
20
15
10
5
August 31
September 2
4
6
8
10
12
14
16
18
20
22
24
26
80
85
90
Azimuth in Degrees

Planet Finder

Ⓒ Ceres

Sept.	1	15
R.A.	$18^{h}44^{m}$	$18^{h}47^{m}$
Dec.	-31°16'	-31°05'
Mag.	+7.5	+7.7



Ⓐ Mercury

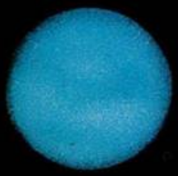
Sept.	1
R.A.	$9^{h}32^{m}$
Dec.	+13°27'
Mag.	+1.0

Ⓑ Mercury

Sept.	15
R.A.	$10^{h}43^{m}$
Dec.	+9°55'
Mag.	-1.0

Ⓜ Mars

Sept.	1	15
R.A.	$13^{h}04^{m}$	$13^{h}39^{m}$
Dec.	-6°42'	-10°17'
Mag.	+1.8	+1.8



Ⓝ Neptune

Sept.	15
R.A.	$16^{h}58^{m}$
Dec.	-21°14'
Mag.	+7.7

SUN

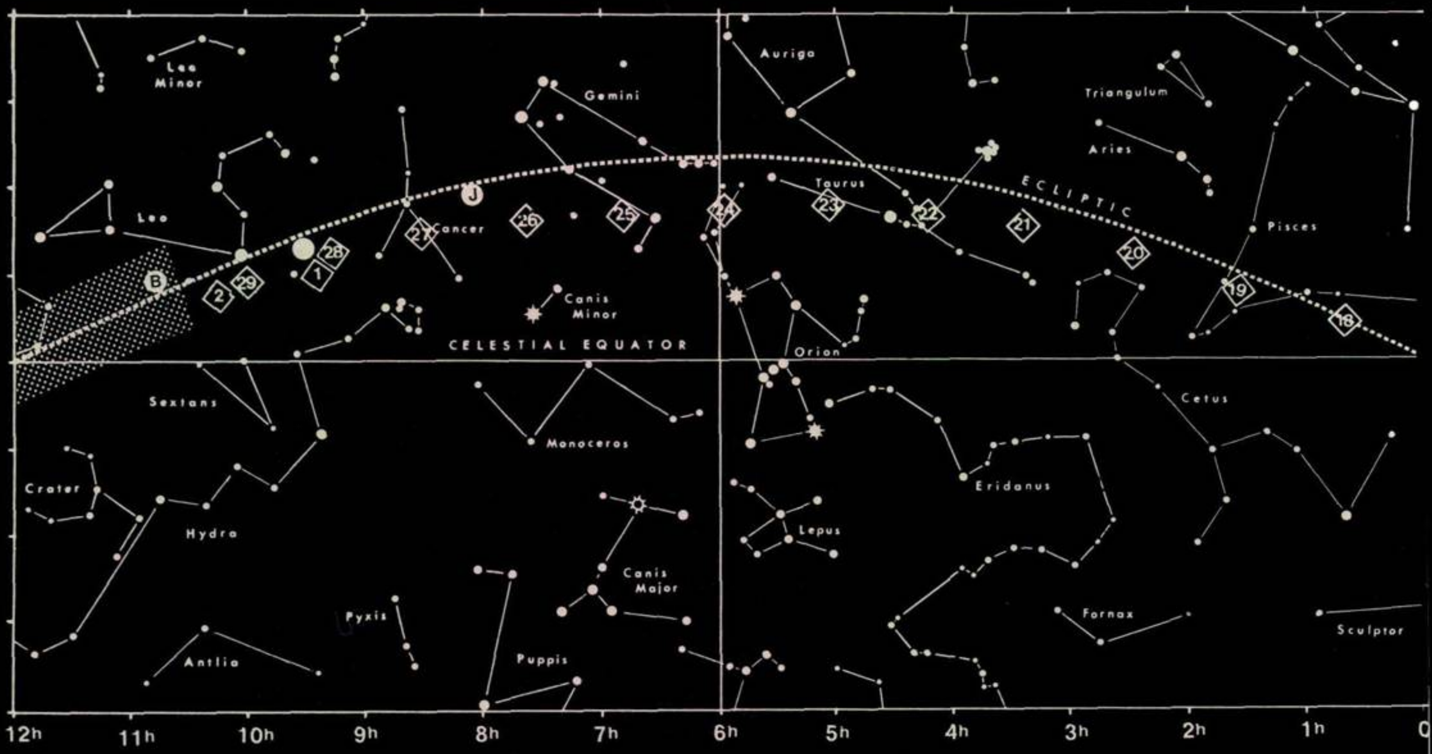
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ Saturn

Sept.	1	15
R.A.	$10^{h}27^{m}$	$10^{h}34^{m}$
Dec.	+11°12'	+10°34'
Mag.	+0.9	+1.0

Ⓤ Uranus

Sept.	15
R.A.	$14^{h}45^{m}$
Dec.	-15°35'
Mag.	+5.7

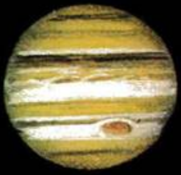

Leo Minor
Gemini
Auriga
Triangulum
Aries
Taurus
ECLIPTIC
Leo
Cancer
Pisces
J
B
1
2
18
19
20
21
22
23
24
25
26
27
28
29
Canis Minor
CELESTIAL EQUATOR
Orion
Sextans
Cetus
Monoceros
Eridanus
Crater
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h
0

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

September 1978

Ⓥ Vesta

Sept.	1	15
R.A.	$16^{h}52^{m}$	$17^{h}11^{m}$
Dec.	-22°18'	-23°22'
Mag.	+6.5	+6.7



Ⓙ Jupiter

Sept.	1	15
R.A.	$8^{h}05^{m}$	$8^{h}16^{m}$
Dec.	+20°33'	+20°01'
Mag.	-1.5	-1.5

Ⓨ Venus

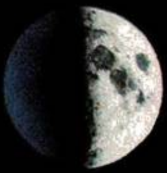
Sept.	1
R.A.	$13^{h}26^{m}$
Dec.	-11°40'
Mag.	-4.0

Ⓩ Venus

Sept.	15
R.A.	$14^{h}11^{m}$
Dec.	-17°29'
Mag.	-4.2

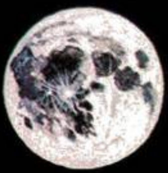
Ⓟ Pluto

Sept.	15
R.A.	$13^{h}21^{m}$
Dec.	+9°19'
Mag.	+14



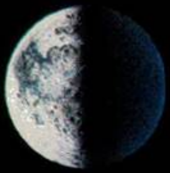
First Quarter

September 9



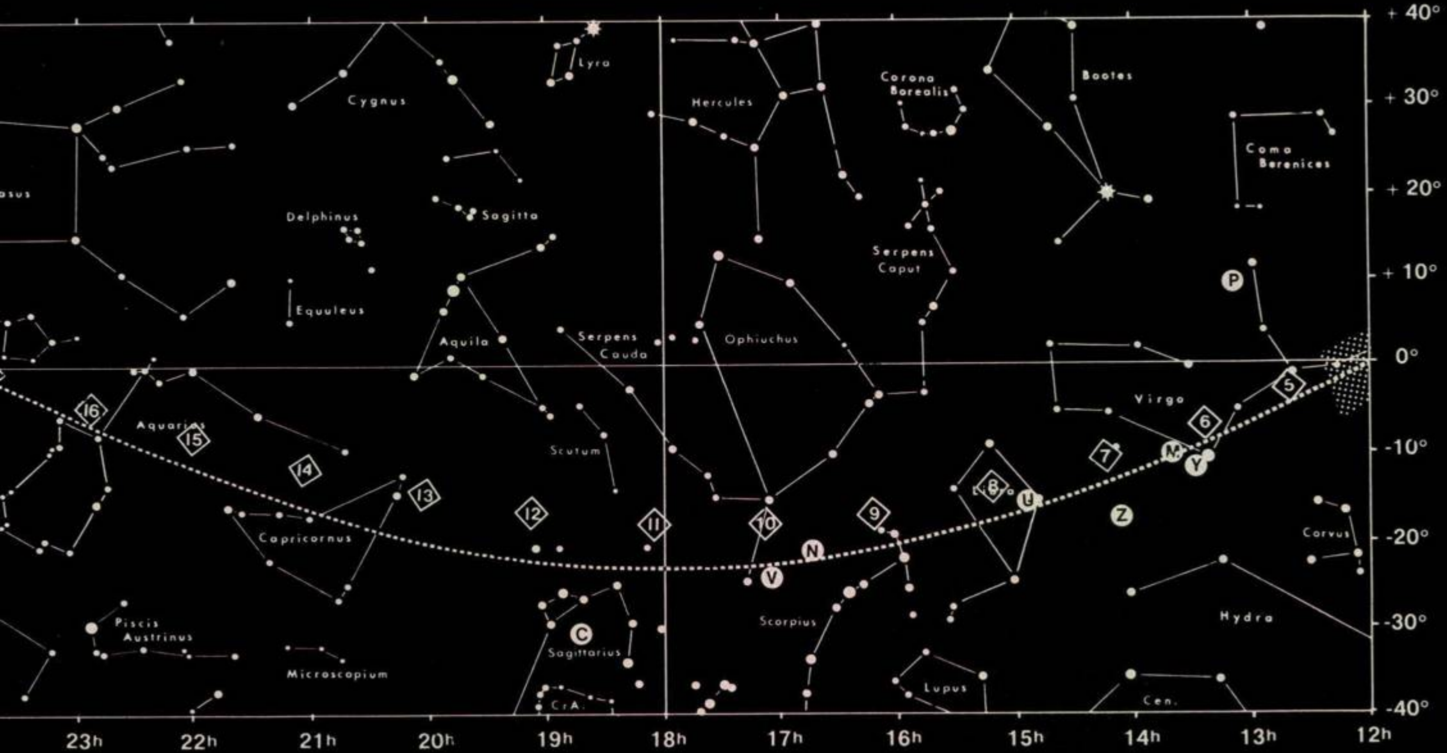
Full Moon

September 16



Last Quarter

September 24



Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
asus
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Scorpius
Hydra
Piscis Austrinus
Sagittarius
Microscopium
Lupus
CrA.
Cen.
16
15
14
13
12
11
10
9
8
7
6
5
P
M
Y
U
Z
N
V
C
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

Left: This shot of Venus (to the right) and Jupiter was taken at 9:00 p.m. on May 26. It's a one second exposure on Ektachrome 200 film using a 50mm lens at f/1.8. Photograph by Harry Klee and Jeffrey Prince. Right: This is another shot of the Venus–Jupiter pair taken 24 hours 43 minutes later (May 27 at 9:43 p.m.). The same equipment and film was used, but because of the time difference this is a 20 second exposure. Photograph by L. H. Price.

up to watch at least a half hour before! At the time of the star's disappearance, the moon will be anywhere from 40 to 65 degrees above the horizon, depending on your location. From Hawaii, the moon will be about 10 degrees up.

If you're in the eastern time zone, you'll have to watch the whole event after sunrise. (To increase contrast between the sky and the objects, look through a red filter; it will darken the blue sky some what.) From the central part of the continent westward, the disappearance happens before sunrise. For the Pacific coast and Hawaii, the whole event, including reappearance of the star from behind the moon's dark limb, occurs before sunrise.

Now for the bad news: If you live south of a line running roughly through Corpus Christi, Tex. and Tampa, Fla., you won't see the occultation. What you will see, though, is the moon sailing just above Aldebaran through the center of the Hyades cluster.

Mars

You'll find it harder to spot Mars this month than Mercury! Its elevation at sunset isn't much higher, and it's almost a full magnitude dimmer (+1.8). Look for Mars low in the southwest at sunset at an altitude ranging from 16 degrees (at the beginning of the month) to 12 degrees (end of the month). On the 8th, the red planet will be just two degrees north of Spica, but neither will be seen very easily.

UPCOMING EVENTS FOR OCTOBER

2 New Moon
7 Uranus passes between Alpha^1 and Alpha^2 Librae
9 First Quarter Moon
11 Mars 0.6 degrees south of Uranus
16 Full Moon
21 Peak date for Orionid meteors
23 Last Quarter Moon
31 New Moon

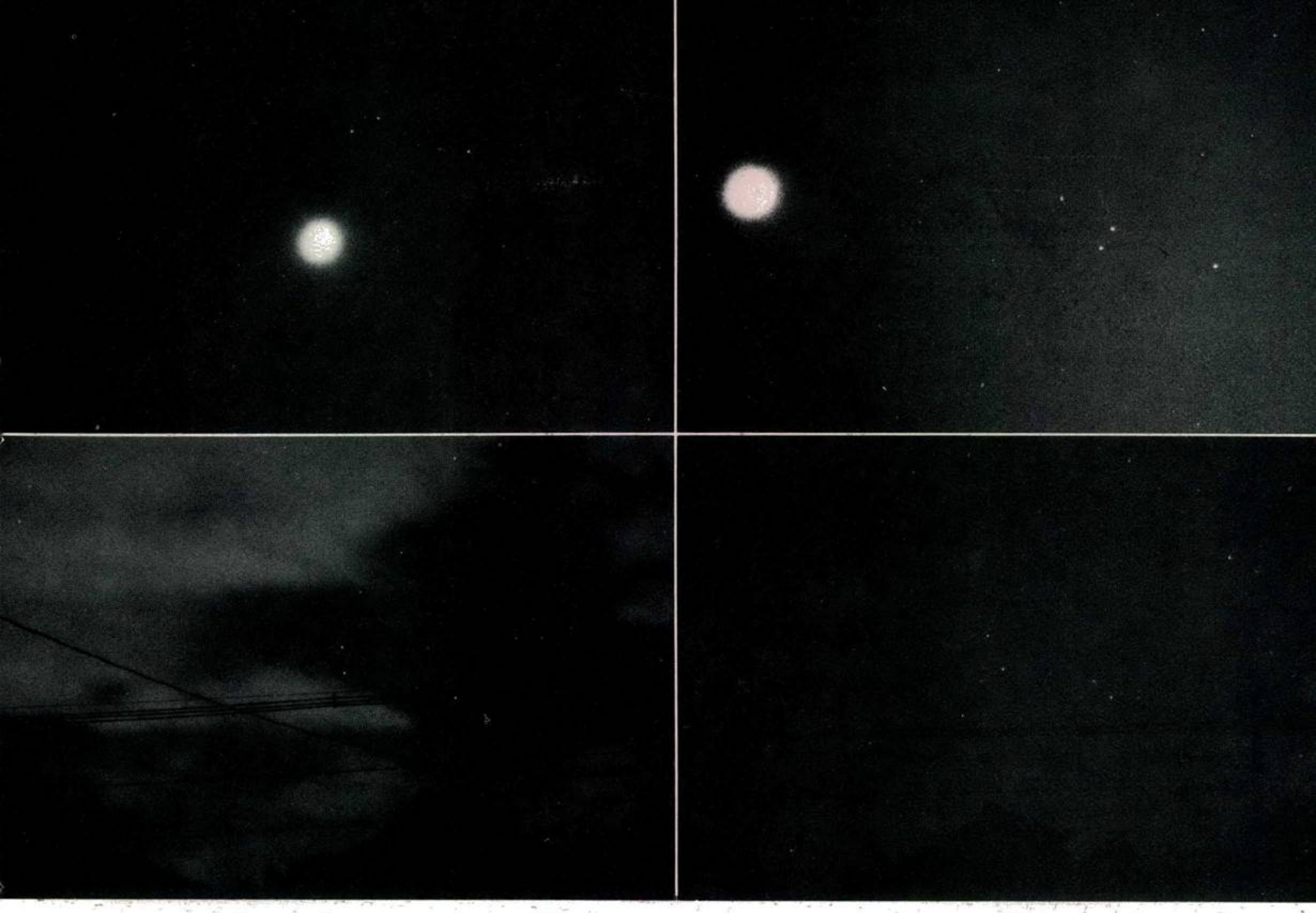
Venus reaches greatest brilliancy on the 3rd, but still will not be very favorably placed due to its low elevation.

On Oct. 7, Uranus will pass between the two components of Alpha Librae. You'll need a telescope to see this — and furthermore the planet and stars will be only 13 degrees high at sunset. Careful preparation and luck are in order here!

Jupiter

Moving eastward through Cancer, Jupiter takes prime position in the morning sky. At magnitude -1.6, it's unmistakable! Rising about 1:30 a.m. (daylight time) on the 15th, it'll be almost due east and 35 degrees high an hour before sunrise. During September, the distance between Earth and Jupiter will decrease by some 33 million miles (53 million kilometers). The visible effect of this will be a brightening of the planet by 1/10 magnitude, and an increase in its equatorial diameter from 31 to 33 seconds of arc.

Jupiter is probably the first object



This sequence of photographs shows the movement of Mars past the star Regulus in the constellation Leo. Note Saturn's position to the right of the pair and the position of the moon in the top photos. The sequence (from left to right, top to bottom) was taken over four nights — June 11 to 14. Each exposure is a five second shot on Tri-X film using a 45mm lens at f/2.8 with a fixed tripod. Photograph by Lester Yuill.

apart from the moon that a beginner looks at, and it's deservedly popular. If you want to recapture what Galileo saw back in 1609 when he turned the world's first astronomical telescope on the heavens, try following the intricate movements of its four bright moons (his "Medicean stars") over a week or two using binoculars only. You'll soon see how fast the inner moons shuttle back and forth, and sometimes the appearance can change noticeably in a few hours!

Saturn

For a while at the beginning of the month, locating Saturn will be difficult because it's very low in the east as the sun comes up. On the 1st, it's only 3-1/2 degrees high at sunrise! But on the 13th, look just to the south of Mercury, and you should be able to make out +1.0 magnitude Saturn about 1/10 degree away from -1.0 magnitude Mercury. If your telescope site has a flat eastern horizon, use a low power eyepiece since you'll likely get both planets in the same field. By Sept. 30, you'll find viewing much easier, because by then Saturn will be about 25 degrees above the horizon at sunrise.

It's always a treat to show someone who has only seen pictures of Saturn the real thing through the telescope; invariably, they gasp with delight! Seeing that tiny perfect image in the eyepiece gives more of a thrill than the best color picture. All this year you are seeing the southern hemisphere and south side of the ring system, and during September the angle the rings make with our line of sight will flatten by 1.8 degree.

Uranus

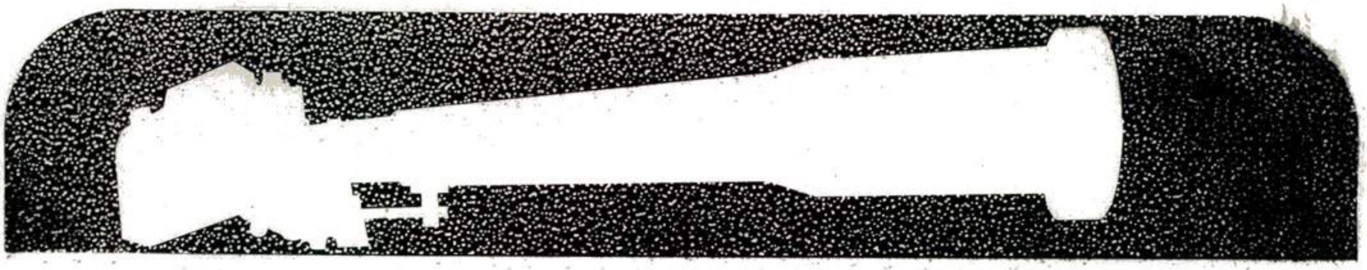
The seventh planet from the sun spends the month closing in slowing on Alpha Librae from the west. What you see as Alpha is really two stars — Alpha^1 and Alpha^2 (read as Alpha one Alpha two). Alpha^2 is the one to the east and is the brighter one as well. (Their magnitudes are 2.8 and 5.2, for a combined magnitude of 2.7.) The pair shares a common direction of motion on the sky, so it's likely that they are physically associated and not just a random juxtaposition in our line of sight. The approach of Uranus should be an easy sight for binoculars, and a telescope with medium power will show a nice contrast between the yellow color of Alpha^1 and the white color of Alpha^2, with the greenish-gray of Uranus.

Neptune

Neptune halts its retrograde loop and resumes direct motion (west to east) at the beginning of September. It's rather dim at magnitude +7.8, and while you can follow its motion in binoculars, you'll need a telescope to make out the 2.4 seconds of arc disk. For all their dimness and small apparent size, the outer gas giant planets do help the observer a bit in that they don't wander all over the sky! If you find them once, reobservation every few weeks will keep you well aware of their motions.

Autumn

For Earth's northern hemisphere, autumn begins Sept. 22. This is the date of the equinox when the sun is at 0 degrees declination, both rising and setting due east and west. From the 22nd on, the sun will increase its southern declination, reaching the limit (-23 degrees and 26.3 minutes of arc) on Dec. 22. Because Earth's climate cannot respond instantly, weather lags about two to three months behind the sun. This expains why summer heat can last into September and why the coldest days often come in February.



PHOTOGRAPHY IN ASTRONOMY

Getting More Out of Your Astrophotography

by
Richard Berry

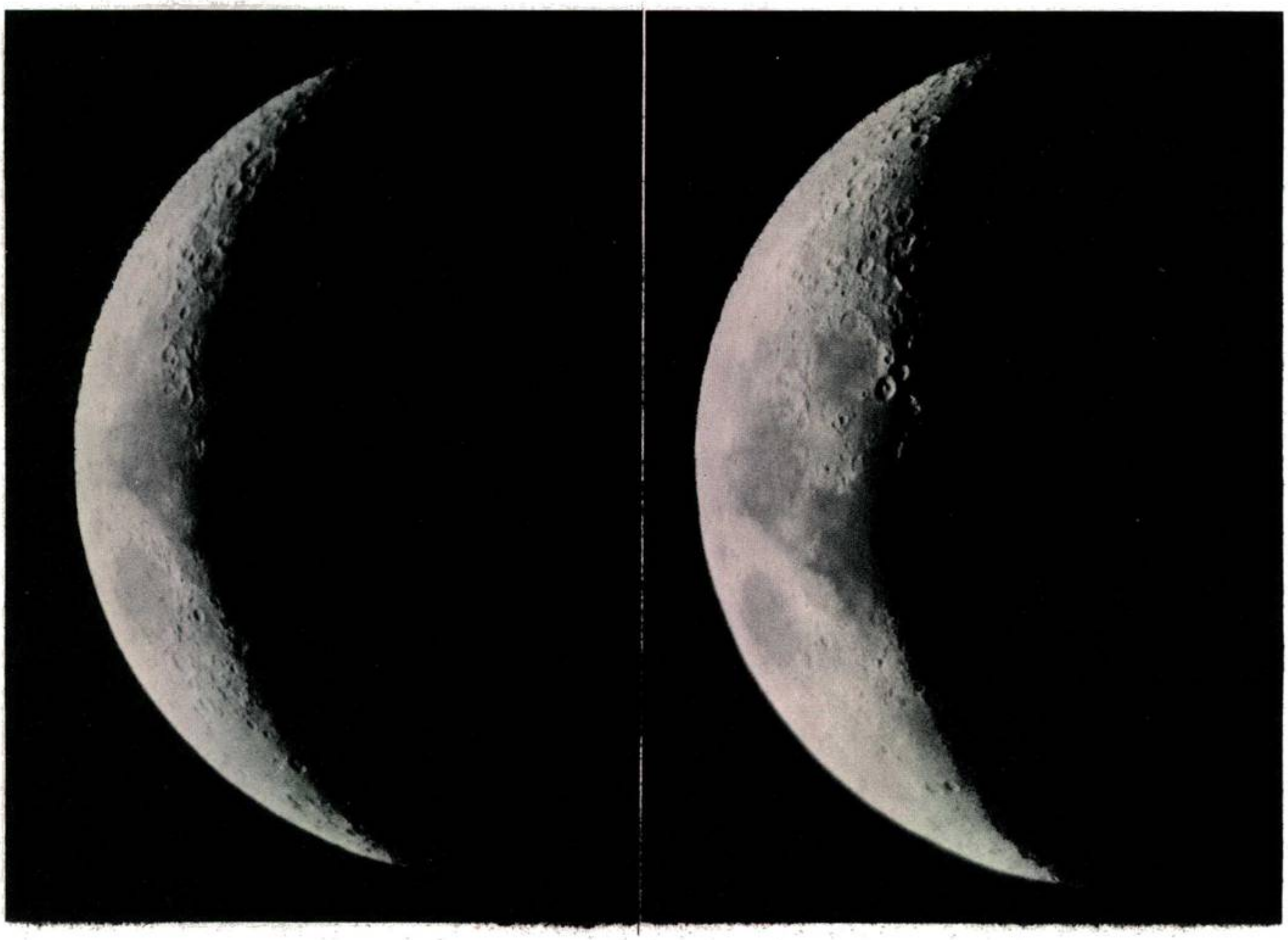
Astrophotography can be a pretty demanding hobby: You face cloudy weather night after night, out-of-focus and underexposed results, and always the discouraging feeling that everybody else's pictures are better than your own. It may seem downright impossible to get any enjoyment or sense of accomplishment from your efforts.

Yet it *is* possible to get a great deal of satisfaction from astrophotography without spending a fortune or owning a 200 inch telescope. You'll find that these five techniques will help make taking pictures of the sky more enjoyable for you.

1st Technique: Know Why You Are Taking Pictures of the Sky — and What You Hope to Accomplish With Them

If your goal is to impress people and make them admire you, that's okay — but you have very tough competition. The people you most want to impress will *always* have seen better results than yours.

If you want to see the sky as your eyes can never see it, or to record details better than memory can hold them, your goal is easily reached and requires only simple equipment. Film has the ability (which the eye does not) to accumulate an image, so that

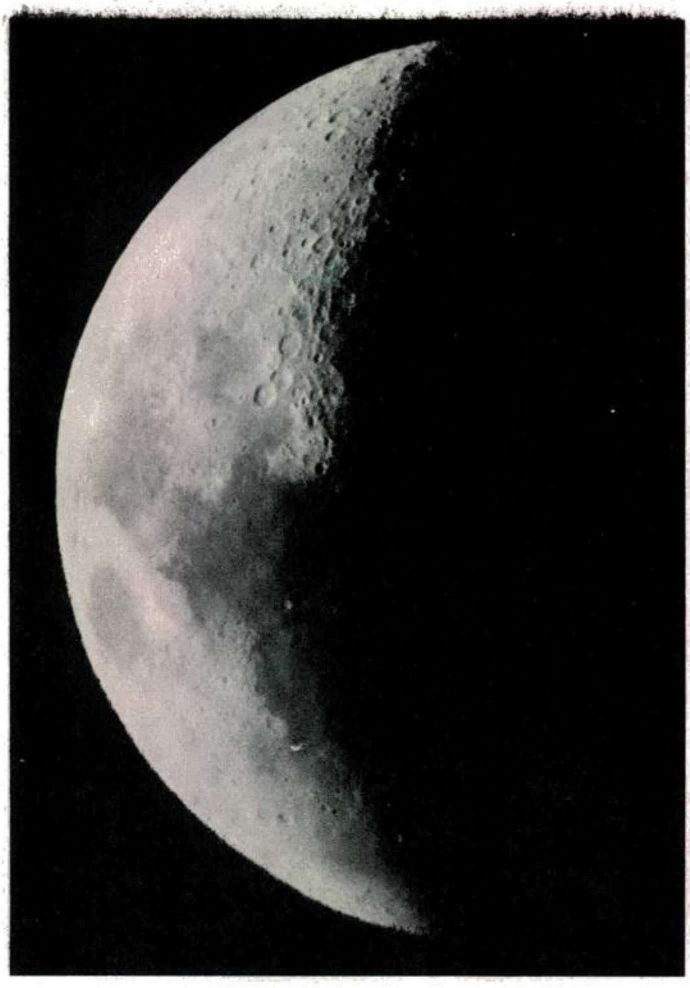


faint nebulae invisible to the eye record on film. Film can record every detail on the moon in a fraction of a second — and hold that detail for centuries.

2nd Technique: Tackle "Do-able" Projects

In tackling a project such as lunar photography or photographing asteroids, the Milky Way or aurorae, you must evaluate what your equipment can do and then pick something do-able. You must consider: *1)* the sky quality where you observe; *2)* characteristics of your equipment; *3)* the quality of your clock drive or hand guiding; *4)* how much time you can afford to devote to the project, and *5)* how much technical know-how you have or can acquire.

If, for instance, you started taking pictures of the Milky Way (because you just had to discover where the brightest parts are, and to see it all in a big composite picture), you might *1)* talk someone into letting you use his farm where the sky is clear and dark; *2)* get a fairly good 35mm camera; *3)* learn to track the sky by hand pretty well for 10 minutes; *4)* devote only a few nights a month to it, and *5)* learn how to develop and print your own film. As time goes on, you could improve items 2 and 3 — eventually using a war surplus lens for exposures up to an hour long. What *is* important is that you have all the necessary equipment and skills to do that *particular* project. It's no fun to bite off more than you can chew, and usually it's more fun to start with something that gives results fairly soon, building up from there.



3rd Technique: Get Feedback From Your Results

If something doesn't work, figure out why. If your moon photos are moved, don't blame it on the film. Is your telescope mount sufficiently stable? If it's too jiggly, fix it or choose a more do-able project. Bad results can be very informative; they will show you what the limits of your equipment are and give clues for improvement. Providing you either modify your goals or improve your equipment, bad results are not wasted effort.

4th Technique: Make the Best "Readout" You Can

Once captured on film, an astrophoto does no good unless transferred to a form you can see and *examine closely.* Professionals usually examine their plates directly, but then their plates are fairly large. You may find prints most satisfying, and may have to learn how to make them. Even if you don't now know how to use an enlarger, it's easy to learn! Most people can get use of one at their school or by joining a camera club. Slides are one answer, but are very expensive compared to black and white prints. If you are seriously interested in *astro*photography, eventually you must learn a lot about photography.

5th Technique: Examine Your Results Thoroughly

Seeing is where the real satisfaction lies — when you sit down and *look at* your photos. As a rule of thumb, spend 10 times as long looking at a photo as you spent taking it. If it takes an hour (total) to get a good moon photo, then look at it dozens of times for months in the future. Each time you'll see more in it. The typical fate of a full moon photograph made with a three inch telescope is pretty desolate. Somebody glances at it, says, "Oh yeah, it's the moon," and forgets it. But look again: How many bright spots (craters) are there? Which ones are they — old, worn ones or fresh ones? Look in an atlas; learn their names. Trace out the rays with tracing paper. Trace the maria. Compare the picture with those taken other months for libration. There are probably about 10 million bits of information in the photograph. Even fuzzy star photos are just crammed full of information about variable stars, possible novae and brightnesses of thousands of stars. It's only through examination that your curiosity and interest will be aroused and then satisfied; in examination you really see what is there to see — as your eyes never could.

Surprisingly modest equipment applied to a "do-able" project can make astrophotography an enjoyable and rewarding experience. In this series of pictures, you can watch the lunar terminator advance from night to night, highlighting new features each night. A complete series would be a fascinating project — and one that's seldom done! These photos were taken with a four inch f/4.5 Astroscan at 16x by the afocal method, using a 200mm telephoto lens simply aimed into the eyepiece. Photographs by Richard Berry.

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Lunar photograph taken by 10 year old amateur astronomer.

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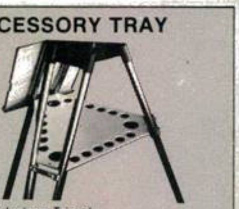

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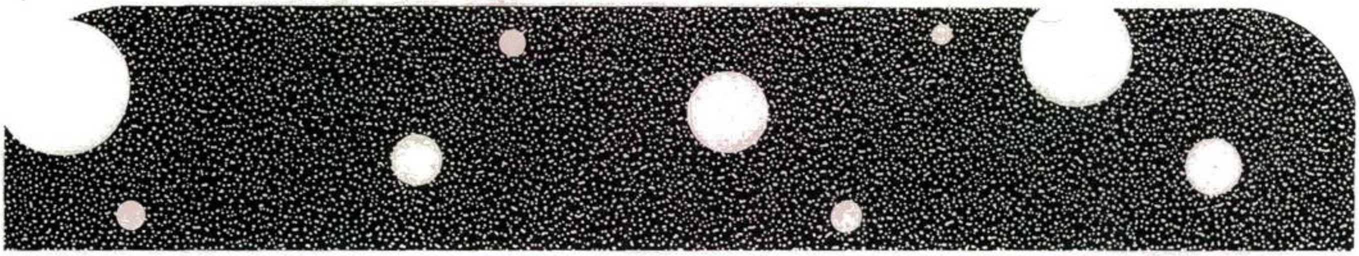


STELLAR FRONTIERS

The Dark Sky Paradox

and

The Origin of the Universe

by

Lee Anne Willson

Everyone wonders, at some time, where the universe came from — whether it began in the far distant past or whether it has always been the same — and if it will someday end.

Not until the second half of the 20th century, with our large telescopes and space probes, have we had the observational clues needed to go beyond speculation to find defensible scientific answers to these ultimate questions.

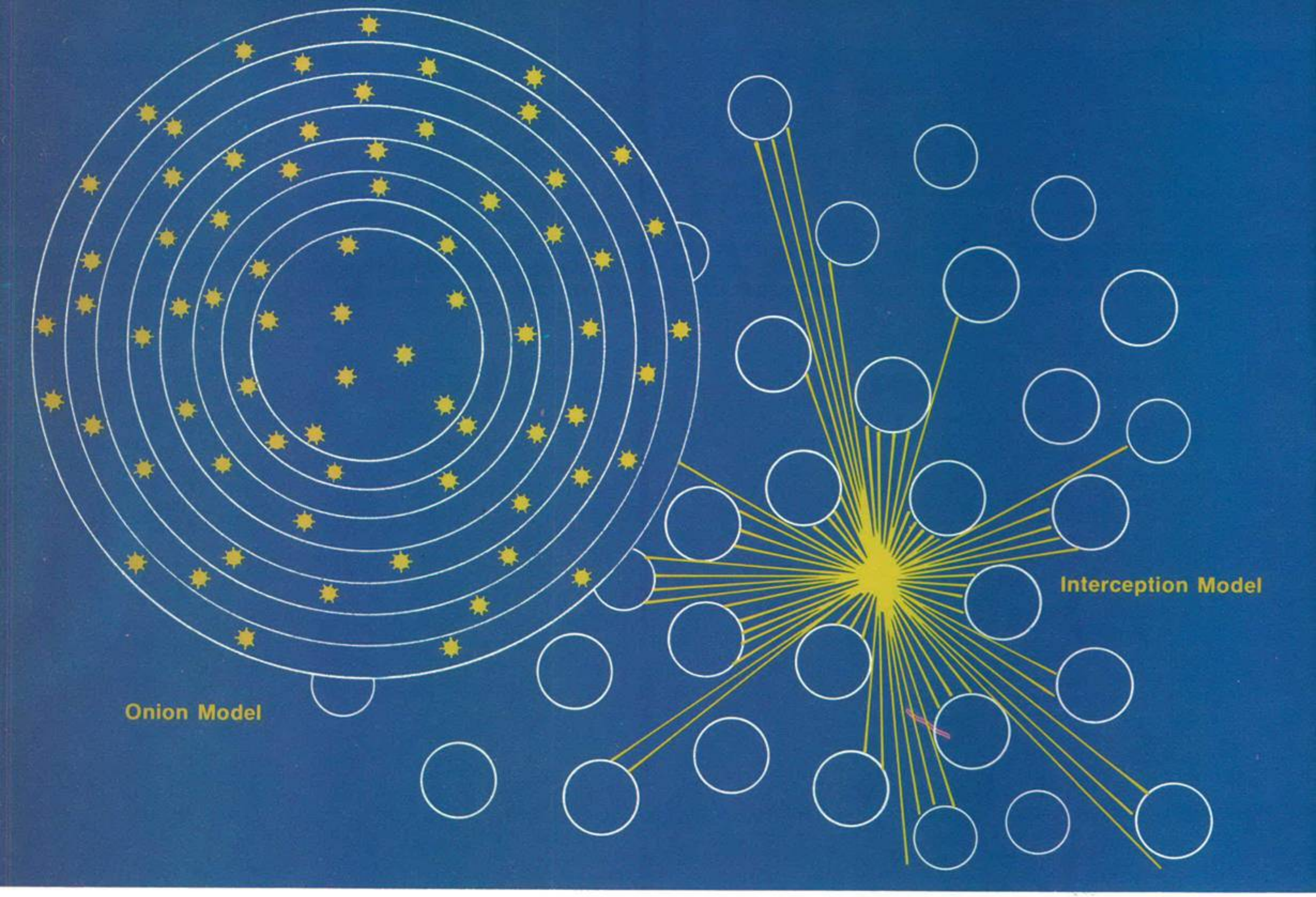
Most observations that are significant insorting cosmological theories require the largest telescopes, the most sophisticated techniques, and the latest equipment for data analysis. Yet there is one very important cosmological observation that anyone can make: *The night sky is dark.*

The realization of the cosmological significance of this simple fact in the 18th century marked the dawn of modern cosmology. If we assume the simplest possible model for the universe — static, infinite and unchanging — and further assume that the universe is filled with stars distributed uniformly and randomly everywhere, a simple deduction leads us to conclude that the entire night sky should be as bright as the surface of the sun. Clearly it isn't. Paradox!

Looking into the star filled universe raises a basic question: "Why is the sky dark at night? Surely, if the universe is filled with stars, then any place I look I'll see a star's surface, and the sky ought to be bright everywhere!" The answer to the question is far reaching. Photograph by Harvard College Observatory.

Two proofs of the paradox are sketched in the illustration on page 54. The first, or "onion" proof, considers a series of concentric shells of equal thickness arranged around the observer like the skins of an onion. Each shell has a larger volume than the one below it, and therefore contains more stars; the number of stars increases as the radius of the shell squared. Each shell is, however, farther from the observer, and the starlight, therefore, is spread out over a larger volume of space — so he observes the light from the stars in that shell decreased through the Inverse Square law by a factor of one divided by the radius squared. The total light reaching the observer from each shell is the number of stars in the shell times the average brightness of each star, or r^2 times $1/r^2$ — that is, the effects of distance and increased volume cancel, so each "onion skin" contributes the same amount of light as every other shell. If there are an infinite number of shells, there must be an infinite amount of light reaching the observer!

This proof neglected the fact that the light from distant stars may be blocked by stars closer to us, since stars are not really point sources of light. The



Both the onion model and the interception model predict that a static, infinite, homogenous universe will have a bright sky. The onion model divides the universe into an imaginary concentric shell around us. Although the light from stars in distant shells drops off by the square root of their distance, the number of stars in each shell rises with the distance squared. The effects cancel, and the model predicts that an infinite flux of light should reach us. The interception model simply posits that in any direction we look, our line of sight should ultimately intercept a star. The universe should therefore look as bright as the surface of a star. Diagram by Richard Berry.

second proof takes this into account: Merely note that in an infinite universe, no matter where we look, eventually we are looking directly at the surface of a star. From this we can conclude that the sky should be not infinitely bright, but only as bright as the surface of the average star — our sun. The difference between these two results is like the difference between worrying about the end of Earth in about five billion years and the possible end of the universe many billions of years later: Both are equally silly.

The significance of the dark night sky was first noticed in the 18th century by Löys de Cheseaux, who only lived to the age of 33. Perhaps partly because of Cheseaux's early demise, the cosmological argument based on the darkness of the night sky has become known as "Olber's paradox" — although Wilhelm Olber's contribution, 80 years later, was merely to reiterate Cheseaux's incorrect explanation for why the night sky is dark after all.

Both Cheseaux and Olbers favored a solution which seems perhaps the most obvious, but which is incorrect: They argued that absorption by interstellar material weakens the light from distant stars. We know there is quite a lot of material between the stars. Some of our most spectacular deep sky objects, like the Orion nebula, are local concentrations of just such dust and gas. Unfortunately, they neglected the basic physical fact that any medium absorbing light will either reradiate it directly or heat up until it can radiate the energy away more efficiently; the efficiency with which an object radiates increases rapidly with increasing temperature. Given an infinitely old universe, the night sky should be bright even with an infinite amount of interstellar gas and dust.

What is the solution to the dark sky paradox? There are many possible mathematical solutions, and each corresponds to a possible universe. Clearly, the universe cannot be static, infinite and unchanging. Assuming that the universe is finite solves the paradox, but produces a limited cosmology and raises unanswerable (and, therefore nonscientific, questions) such as, "What is beyond the edge of the universe?" Another variation on this is an infinite universe with only a finite number of stars. Unfortunately that would put us in a very special position: the star filled portion. This is very unappealing to cosmologists wanting to make the simplest possible assumptions about the universe. Our place in it cannot be special!

Clearly, if we want to resolve Olber's paradox, we must look for further observational evidence to provide clues as to which of those simple, basic assumptions could be wrong. At this point we must turn to evidence provided by the large telescopes and sophisticated techniques mentioned earlier.

When the 100 inch telescope on Mount Wilson was new, it was the best and biggest in the world; Edwin Hubble used it to study the farthest, faintest galaxies he could find. He discovered the amazing fact that distant galaxies appear to be receding from us — the farther away, the faster they recede. Hubble's law actually relates the shift of the galaxy's spectrum to longer wavelengths — its redshift to its distance.

The distance is measured by the size and brightness of the galaxies — assuming they are basically the same as nearby galaxies. The correlation between galaxian angular size and redshift is excellent, as it is between brightness and redshift. There's little doubt that the larger the redshift, the more distant the galaxy. Since the simplest explanation for any redshift is the Doppler effect due to motion of the source of light, Hubble's law suggests that the universe is expanding.

The observation of a relationship between velocity and distance for distant objects is our second fundamental cosmological observation. There are a couple of other interesting consequences of this observed redshift that are worth mentioning here. First, when light is shifted to the red, it is weakened; we will measure it to have less energy than it had before the redshift. Thus the light from very distant galaxies becomes weaker both because it is spread out over a larger and larger volume of space (the Inverse Square law) and also because it is redshifted. Presumably, if we looked far enough away, we could see objects redshifted to nearly zero energy. Where the speed of the receding object equals the speed of light, the redshift to zero energy takes place. This gives the second consequence: We can never hope to observe past the point where the energy becomes zero, and will therefore never be able to find out what lies beyond. This "edge-of-the-universe" distance lies between 10 and 20 billion light-years away. We can only assume, for simplicity's sake, that what lies beyond is the same as what we see.

Hubble's law is observational evidence that one of the assumptions used in deriving the dark sky paradox was untrue. The universe is not static. This leads to several dynamic dark sky cosmologies, including the big bang and the steady state.

The big bang theory avoids Olber's paradox in two ways: by making the more distant galaxies redder, and hence fainter, via Hubble's law, and by making the age of the universe finite.

We make the simplest possible interpretation of the expansion of the universe in big bang cosmology: We assume that some 10 to 20 billion years ago the universe was compressed into a dense, hot plasma. For some reason the universe then exploded, and as the hot plasma cooled, it collected into galaxies with vast spaces between. The galaxies we see receding today were set in motion by that initial explosion. This also implies that someday in the far distant future, the big bang universe must come to an end, if not in a dramatic collapse and implosion, then at least a winding down and a running out of fuel until all is quiet, dark and mostly empty space.

The steady state theory, on the other hand, asserts that the universe always was and always will be the same as it is now. This is an appealing thought, since it avoids those very difficult questions: "What happened before the big bang?" and "What made it explode anyway?"

To take into account Hubble's law, the steady state theory must assume that the universe is, was, and always will be expanding. In order to keep the average distance between stars the same in an expanding universe, new stars, gas and galaxies must come into existence as the universe expands. Somehow, therefore, the steady state theory demands new matter to come into existence between the stars to maintain the supply of stars in the universe. This violates one of the most fundamental of physical laws — conservation of matter and energy — but only just barely. The rate at which matter must be created amounts to only about 15 hydrogen atoms per cubic mile each year; for comparison, one cubic mile of ocean contains 200,000,000,000,000,000,000,000,000,000,000,000,000 hydrogen atoms, and even a cubic mile of "empty space" already contains more than 100,000,000,000,000 hydrogen atoms. There is no real way for us to test in the laboratory whether conservation of matter and energy holds to this degree, especially since the cosmologist is free to assume that very special conditions need to be satisfied before the matter will spontaneously appear (such as "no matter at all within 50 light-years").

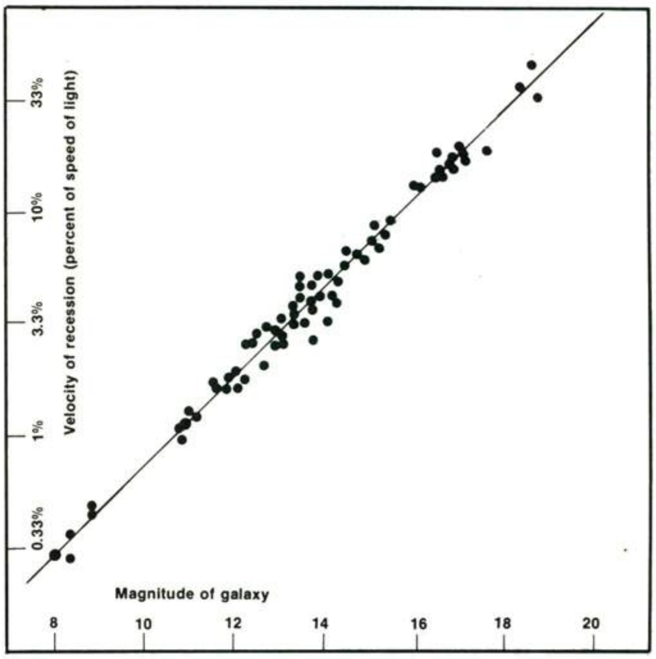
Most astronomers today will tell you that the steady state theory is dead. Evidence supporting this conclusion includes some very technical arguments as well as some fairly direct observational evidence. Many of the technical arguments are not very convincing taken singly, but all together make a good case for the big bang. The single observation which is usually presented as clinching the argument deserves some discussion: It is the 1964 discovery by Arno A. Penzias and Robert W. Wilson of the cosmic microwave background. This is sometimes called the "three degree" background because the sky radiates just as much energy as we expect from "an ideal radiator at a temperture three degrees Celsius above absolute zero". Another way to say this is that the sky has a temperature of three degrees (in the Kelvin or "absolute" scale). This amounts to answering the question, "Exactly how dark is the dark night sky, anyway?"

All obects radiate energy unless they are at absolute zero. The amount of energy radiated increases drastically with increased temperature: Doubling the temperature (on the absolute scale) increases the energy radiated sixteen-fold. Thus the temperature and the amount of energy radiated are related. The temperature also determines another property of the radiation: its "color". An object at room temperature — even hot stovetop temperature — radiates mostly in the infrared. That's why we sometimes call infrared radiation "heat rays". The sun, which is obviously considerably hotter, radiates most of its energy in the form of visible light. A very hot star, some 10 times as hot as the sun, radiates mostly in the blue-violet. This leads to the apparently contradictory fact that cool stars have "warm" colors (red and yellow) and hot stars have "cool" colors (white and blue)!

Not only is the energy of the three degree background radiation just right for an object at three degrees, but its peak output is in the microwave region just where it ought to be. In the big bang theory, the microwave background appears naturally as leftover and cooled down radiation from the big bang itself. In fact, the presence of such radiation, with energy and color corresponding to a temperature of about three degrees, was predicted by big bang theorists *before* the microwave background was observed. This is a very important point. Scientists tend to believe theories which *predict* experimental results much more than theories which merely *explain* them after the fact. The reason for this is that any result can be explained with infinitely many theories, but only a few of those theories (including "the correct one") will predict the results of experiments yet undone. Since the big bang theory predicted the three degree background, and that background was subsequently observed, the big bang looks like a good bet.

This preference for predictions is a very reasonable and practical bias, but it can occasionally lead us astray. It should not cause us to reject a theory which could have predicted a result had anyone been clever enough to do so ahead of time. Might it be that the steady state could have predicted the microwave background? Indeed it could have, and the key to making the prediction is a careful consideration of why the night sky is dark.

We made two tacit assumptions (which we didn't mention) in deriving Olber's paradox. One was the underlying assumption of all astrophysics that the laws of nature tested in laboratories on Earth apply to the entire universe. This may seem arrogant, but it's absolutely necessary to make this assumption in order to make any progress at all in understanding the heavens. In fact, the birth of modern astrophysics can be said to have occurred when Newton made the mental leap that connected the moon's motion in its orbit with the apple falling in his orchard. So much success has been achieved with this assumption, and so much unfettered and untestable speculation is possible without it, that astrophysicists would rather build complicated theories using only known physical laws than accept a simple and elegant solution which "bends" laws even a little. The assumption is so basic to astrophysics that it is very seldom stated or even consciously considered.



Plotting the brightness of distant galaxies against their redshift gives evidence for the expansion of the universe. As long as galaxies are the same throughout the universe (that is, the average luminosity of galaxies in different parts of the universe is assumed to be the same), then this plot shows the distant galaxies — the faintest ones — receding most rapidly. At exceedingly great "look-back" times, this brightness-redshift relation may break down because galaxies were not then the same as they are now.

For this reason, we reject immediately one possible solution to the dark sky paradox: the "tired light" hypothesis, which suggests that light from distant objects gets tired (redder) and finally gives up (doesn't reach us), even though we don't see any such effect in the laboratory. The tired light solution can also be ruled out more rigorously by noticing that it doesn't lead to a "steady state" universe. In a static universe there is no source of supply for new stars, and no garbage dump for getting rid of old ones. Because all stars age, the appearance of the static universe must change.

The second tacit assumption of Olber's paradox is that all stars last forever. We made this assumption when we took the universe to be unchanging, and also when we added in the contribution from very distant stars. Because light travels "only" 300,000 kilometers each second, or one light-year per year, when we look very far away we are also looking into the distant past.

To get a bright night sky in a static universe where the stars have finite lifetimes, we have to assume that as we look farther away in space we see stars which "turned on" sooner, in order to give their light a chance to reach us. Otherwise, if we assume that all stars turned on more or less at the same time (say five billion years ago), then as we look farther away (beyond five billion light-years) we see only stars which have not yet begun to shine — and the night sky will be dark between the stars. But this is *not* a proper steady state model because there is a time "before" and another time "after" when the universe is dark and no stars shine. The bright sky version is even worse because it places the observer at a very special place — the only place in the universe from which the sky is bright — and the appearance of the universe is also different at different times.

We are thus forced to consider only those steady state cosmologies in which somehow new stars are continually formed — either through "backwards" processing of material to rejuvenate stars (which violates so many physical principles it would give any physicist nightmares), or by allowing the universe to expand (as it is apparently doing) and letting new material appear from nothing to provide the raw materials for new stars.

We are now ready to make our prediction. We'll take into account the finite lifetimes of stars to find how bright the night sky should be in a steady state universe which appears the same as our universe does today. The simplest way to determine this is to use the famous Einstein mass-energy relation, $E = mc^2$ If all the matter in the universe were to be suddenly converted into energy, the amount of energy, by $E = mc^2$, distributed throughout the universe, would be equivalent to a night sky temperature of only about 20 degrees Kelvin instead of the 6,000 degrees Kelvin or so found in the bright sky paradox.

It's really not reasonable, however, to assume that all matter in the universe will instantly convert to energy. What really happens is that roughly 10 perent of the hydrogen in the universe is converted, via fusion processes in stars, to helium with a net energy output of $E = 0.0007\,mc^2$ over the lifetime of the star. The 10 percent comes from detailed calculations of the nuclear reactions which occur in the interiors of stars. Using this number and our best estimates for the density of matter in the universe gives us — miraculously — a night sky temperature of three degrees!

However, there is a catch: The steady state theory three degree background has the right energy to fit the observations but not the right color. Many outstanding cosmologists have tried — but failed — to find a means for the light from distant galaxies to be changed from essentially white pinpoints on a black background to a uniform "red" (microwave) sky. This failure to find a physical mechanism to fix the color of the background radiation in the steady state theory has converted even its original author, Sir Fred Hoyle, into a reluctant believer in the big bang. Philosophically speaking, however, a mere failure to find a mechanism is not the strongest possible argument; maybe no one has yet been clever enough to see the trick the universe uses.

Now that we've raised a possible doubt about astronomers' favorite argument for preferring the big bang, we must ask the question: What other observational evidence supports the big bang theory over the steady state? Several cosmological observations have been made which appear to favor the big bang — enough so that it's extremely unlikely that you'll find a astronomer today who will admit publicly to preferring the steady state theory. The crux of all these tests is the observation of galaxies or other sources as far as possible from us. Because light travels only one light-year per year, the farther away we look in space, the older the light that reaches us. By looking at the most distant objects, we can hope to observe an early era when — at least according to the big bang theory — things were different than they are now. By measuring the velocity of recession of distant galaxies, we can look for evidence that the Hubble expansion might be slowing down; by counting the number of very distant galaxies, we can try to determine if galaxies were once closer together; by looking for oddball objects — like quasars — at large distances, we can learn if there were other kinds of objects around before there were galaxies like our own. All these tests currently yield results which are positive — yes, the universe is evolving — but just barely. The techniques are sophisticated and the analyses must be carefully made; not many astronomers have both time and inclination to pursue these studies, and access to the equipment needed to carry them out. Probably we do in fact see evidence that the universe is evolving, but there is still room for a small amount of doubt.

The simplest of all possible cosmological observations — the darkness of the night sky –thus leads us to a very intriguing comparison of the leading cosmological theories of today. The conclusion, perhaps surprising, is that both major theories agree in predicting the total energy of the three degree cosmic background radiation.

The widespread belief in the big bang is presently justified by two arguments: The "color" of the microwave background, and the fact that numerous individually marginal observations all point to the same conclusion: The big bang theory is the best bet.

Lee Anne Willson is an assistant professor of physics at Iowa State University, and previously worked in the astronomy department at the University of Washington. Her research interests center on the study of variable stars. She has contributed to ASTRONOMY before (see "Why Do Planets Have Rings?", December 1977).

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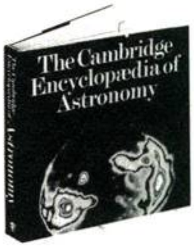

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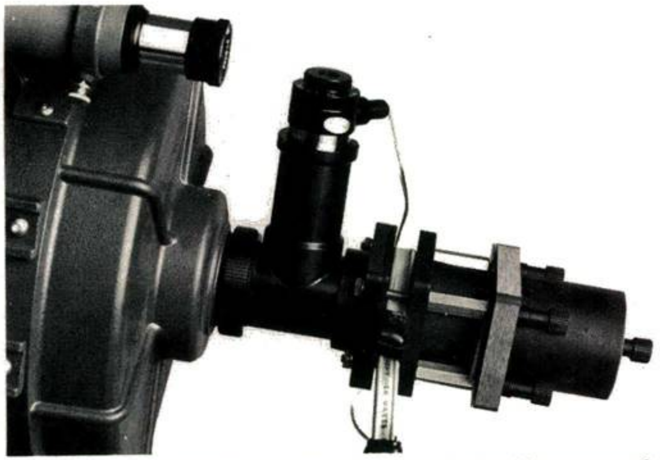

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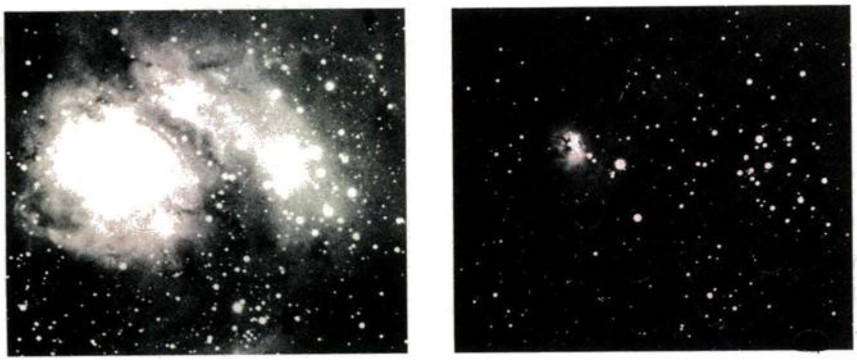

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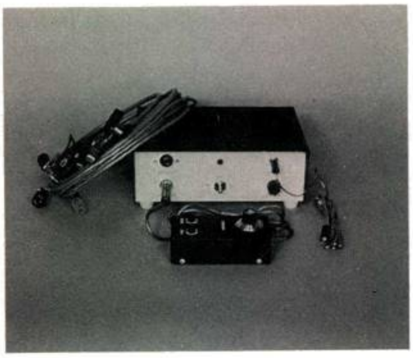

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Studies of Photographic Plates Reveal Moon Orbiting Pluto

Astronomers have discovered a moon orbiting Pluto, the ninth and most distant of the solar system planets.

On June 22, U.S. Naval Observatory astronomer James W. Christy was examining photograph plates of Pluto made in April and May, using the observatory's 61 inch telescope in Flagstaff, Ariz. He noticed the image of Pluto was elongated — something that can happen when observing conditions or the plate is bad. If that was the case, the images of stars near Pluto should also have been blurred, but they were normal. Christy then checked the observatory's files and studied plates taken in 1965 and 1970, noting a similar elongation. Convinced that the elongation was too great to be a feature of the planet, he proposed a likely explanation: Pluto has a small satellite in an extremely close orbit.

Shown here is the newly discovered moon of Pluto, previously thought to be an unusual surface feature. Because Pluto orbits on its side, the moon travels in a north-south orientation to observers on Earth. It was discovered on photographic plates taken with the U.S. Naval Observatory's 61 inch astrometric reflector in Flagstaff, Ariz. U.S. Naval Observatory photograph.

Pluto is 2.8 billion miles (4.4 billion kilometers) from Earth, and has an estimated diameter of 1,500 miles (2,400km), considerably smaller than previously believed. The new satellite is approximately 500 to 600 miles in diameter and 12,000 miles from Pluto. In comparison, our moon is about 240,000 miles from Earth. Because the satellite is so close to the planet, it's extremely difficult to observe photographically. Only during part of its period of revolution (6 days 9 hours and 17 minutes) is the satellite separated enough from Pluto to permit its detection with the largest telescopes — and only under the best observing conditions. It's hoped that the Kitt Peak National Observatory and Hale Observatory's 200 inch telescope on Mount Palomar can be used for a closer look.

Officially, the moon has been designated 1978-P-1, but Christy suggested Charon as the permanent name. In Greek mythology, Charon was the name of the boatman who ferried the souls of the dead across the river Styx into the underworld where Pluto reigned as god.

According to Dr. Robert Harrington of the observatory staff, the rotation of the planet and moon correspond, which means an observer on Pluto would always see the moon in the same spot in the sky. Also, Pluto rotates on its side, so Charon would appear to

Pluto *continued on page 62*

Pulsar Numbers Double

Radio astronomers in Australia have discovered 155 new pulsars, doubling the previously known number of these regularly flashing radio sources that are believed to mark the remains of "dead" stars.

The discovery is forcing astronomers to revise their theories of how stars die, because pulsars are far more numerous than existing theories predict. Instead of being formed only in supernova explosions (the previously accepted origin of pulsars), it seems many must additionally be formed by large stars that bow out "not with a bang, but with a whimper".

The new crop of pulsars was discovered by an international team of astronomers including Dr. Joe Taylor of the University of Massachusetts, Dr. Andrew Lyne of Jodrell Bank, Dr. Richard Manchester of the Commonwealth Scientific and Industrial Research Organization in Australia, and Drs. John Durdin, Michael Large, and Alec Little of the University of Sydney. The astronomers combined their experience from three previous pulsar surveys made at Jodrell Bank, Arecibo, and Molonglo, Australia. The Mills Cross radio telescope at Molonglo, near Canberra in New South Wales, was used for this latest and most comprehensive survey. The astronomers surveyed 2/3 of the entire sky, from declinations +20 degrees down to -85 degrees, during a three month period in 1977, and analyzed the observations by computer. The pulsars discovered were then examined individually with the 210 foot (70m) dish at Parkes, New South Wales, to determine their precise coordinates, pulsation periods, and other data.

A total of 224 pulsars were observed during the survey, of which 155 turned out to be new discoveries, bringing the total number of known pulsars to over 300. Among these is the slowest pulsar known, PSR 1845-19 in the constellation Sagittarius, with a pulse period of 4.3 seconds. None of the new pulsars flashes particularly quickly; the fastest pulsar in this new group flashes every 0.13 seconds.

"The object of the Molonglo survey was to count the number of pulsars throughout the galaxy," said Lyne. From the Molonglo results, he estimates that the galaxy contains a total of one to two million pulsars — at least four times more than previously believed — which implies a pulsar production rate of one every four years. Where are all these pulsars coming from?

According to current ideas, a star like our sun will quietly shrink at the end of its life to become a tiny white dwarf, about the size of Earth. Stars larger than the sun, the theory goes, will erupt at the end of their lives in supernova explosions, leaving behind a highly compressed neutron star about 15 miles (24km) across, or an invisible black hole.

A neutron star consists of matter crushed billions of times more densely than anything on Earth. Black holes are even more bizarre. They are caused when an object shrinks past the neutron star stage and its gravitational pull becomes so strong that nothing — not even light — can escape, thus making the dead star invisible to the "outside world".

The existence of black holes is still controversial, but astronomers agree that neutron stars and pulsars are the same thing; the rapid radio pulses which are characteristic of a pulsar are emitted like a lighthouse beam each time the neutron star spins (approximately once per second).

But supernovae do not seem to go off in our galaxy nearly often enough to account for the observed number of pulsars. The last supernova observed in our galaxy was in 1604; even if we assume that most supernovae are obscured by galactic dust so that they go undetected, theorists are still hard pressed to account for a supernova rate of more than two or three per century, similar to that observed in other galaxies.

The problem of pulsar birthrates is aggravated by the fact that pulsars seem to have shorter lifetimes than previously thought. Lifetimes of about 10 million years have been estimated from their rate of spin (which slows down as the pulsar ages), but many of them are moving so fast through space that they would already have left the galaxy had they been that old. According to Lyne's lastest calculations, a pulsar's lifetime is typically four million years, after which its radio emission fades out. The shorter the average lifetime of pulsars, the more often they must be produced to account for the observed numbers.

"It's a difficulty that can't be swept under the carpet," said Prof. Tony Hewish of Cambridge, who won the Nobel prize for his part in the discovery of pulsars in 1967. "You have to start asking questions like: 'Can neutron stars form without a supernova explosion?'."

At this time theorists don't have the answers; they are having to face the possibility that big stars do not all die in a supernova's blaze of glory, as previously assumed, but that many of them quietly collapse down into neutron stars at the end of their lives. An alternative suggestion is that a supernova might give rise to more than one neutron star, each of which then speeds away from the others.

This theory is not widely supported, but it demonstrates the extremes to which astronomers are having to go to explain the new pulsar observations. Whatever the answers, it will throw important new light on the late stages of the evolution of massive stars and the production of supernovae.

Pluto *continued from page 61*

Earth observers to be in a north-south orbit.

Having a satellite to observe around a planet makes it possible to learn something about the weight, mass and composition of the planet itself. The orbit of Charon indicates for the first time that Pluto itself is very small and light. Pluto weighs only 2/10 percent as much as Earth does. This means Pluto has a density only slightly greater than water — not what you'd expect if it were made of solid rock — and might be similar in composition to major outer planets (Jupiter, Saturn, Uranus and Neptune).

Pluto is somewhat egg shaped, a characteristic of large asteroids and small moons of other planets. It's speculated that Pluto may have started out as a satellite of Neptune, with a chunk coming along with it that became Charon.

If Pluto is as light as they say, something else must be perturbing the orbits of the outer planets. This leaves open many interesting possibilities.

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Problems With Tank, Hoist Delay Shuttle Vibration Tests

Launch vibration tests of the Space Shuttle Enterprise started May 31, more than a full month behind schedule.

Delays were caused by difficulties in hoisting the Enterprise and external tank, and by an accidental denting of the tank.

The mated vertical ground vibration tests will simulate vibrations the Shuttle will feel during its eight minute launch. Engineers are looking for potential sympathetic vibrations that could cause structural damage — even breakup — or scramble the Shuttle's electronic brains. The vibrations are similar to those encountered when an out-of-balance auto tire causes other parts of the car to shake with it.

The tests mark the first time that the Shuttle orbiter, external tank and solid rocket booster have been joined together.

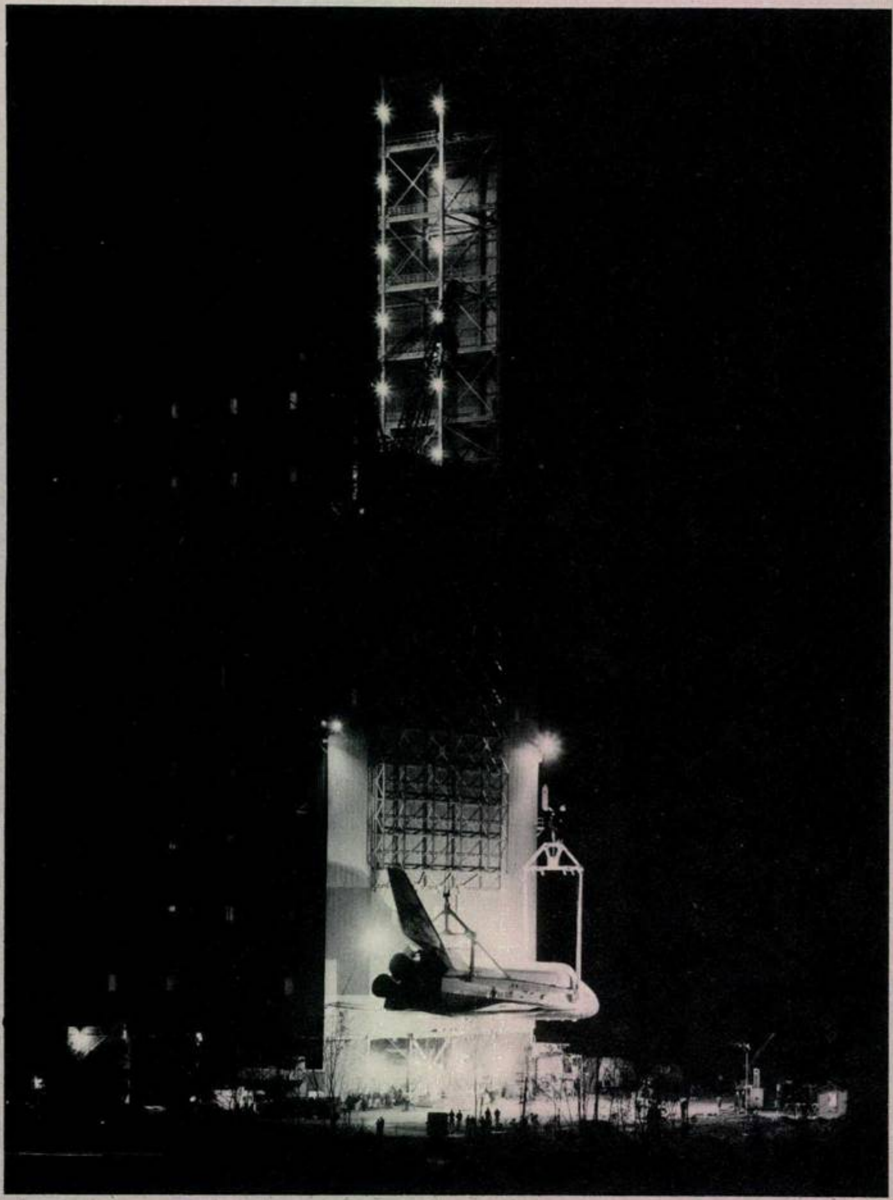
The first test sequence, with just the orbiter and tank, was delayed. Initial attempts to hoist the two into a test stand were postponed because of broken hydraulic equipment. However, the Enterprise was finally installed on the tank in the test stand on April 21.

Rains caused further delays, hampering technicians as they installed sensors.

The most serious, though, was a dent that occurred during the first attempt to start up. Water (to simulate liquid oxygen at various levels) was being pumped into the tank when part of the tank dimpled inward. The area, which covered several square feet, was immediately popped out by pressurizing to one pound per square inch above atmospheric pressure. Tests were again delayed while the tank was recertified.

The problem was traced to high winds around the tank vent atop the test stand. As water was pumped in, air was displaced. High winds around the vent caused low pressure — in effect sucking the air out too fast, and causing the thin tank to dimple.

The vibration tests are to be completed in November, and include mounting the Shuttle orbiter and tank on solid rocket boosters filled with inert propellant.



Here, the Enterprise was being readied for hoisting into the dynamic test stand at NASA's Marshall Space Flight Center in Huntsville, Ala. The shuttle was being prepared for a series of ground vibration tests scheduled to last through the rest of the year. NASA photograph.

European Launchers May Compete With US Space Shuttle

The European Space Agency (ESA) has authorized production of its first five operational Ariane launch vehicles, amidst talk that the throw-away rocket will be involved in a price war with America's reusable Space Shuttle.

Ariane is to become Europe's first regularly used launch vehicle. Its capability will be roughly between that of America's Atlas-Centaur and Titan III-C. Although it will not be capable of launching manned spacecraft, it's openly intended for the lucrative communications satellite business.

Both ESA and NASA are seeking to have the International Telecommunications Consortium (Intelsat) commit its Intelsat V series to their respective launchers. While NASA refrains from

Ariane *continued on page 65*

Pioneer Venus Detects Gamma Ray "Bursts"

Scientists have confirmed that Pioneer Venus 1, on the first leg of its seven month voyage to Venus, detected an extremely powerful "burst" of gamma rays from somewhere in the universe.

So-called gamma ray bursts, unknown until 1973, have enormous energies and occur about once per month, seemingly from random points in our galaxy or even beyond. Discovery of their origin — black holes, brilliant supernovae, neutron stars or some totally unexpected source — represents one of astronomy's most difficult tasks. Over the course of its 300 million mile (482 million kilometer) mission, Pioneer Venus' measurements of these puzzling bursts should enable scientists for the first time to accurately track their origins.

Designed to orbit Venus to study its weather processes, Pioneer Venus 1 carries six interplanetary instruments including a 6.4 pound gamma ray burst detector. The instrument's twin sodium iodide detectors sensed a "classical" two second pulse of these very high energy photons just 33 hours after lift-off and 351,000 miles (585,000km) from Earth.

Pioneer Venus 1 and its companion Pioneer Venus 2 (a multiprobe spacecraft) are managed by NASA's Ames Research Center in Mountain View, Calif. Both will arrive at the cloud shrouded planet in early December.

Two other American spacecraft also detected the gamma ray blast — Vela, a Department of Energy satellite circling Earth and Helios B, a NASA-European scientific satellite orbiting the sun. Scientists will correlate the observations of the Venus orbiter with these satellites' data to obtain a rough "fix" on the burst. As Pioneer Venus 1 speeds toward Venus, away from Earth satellites, such "triangulation" techniques will pinpoint the origin of gamma ray bursts with ever-increasing accuracy.

Ideally, measurements of the gamma ray sources will be made with an accuracy of less than one minute of arc, precise enough for an attempt at identifying the source with powerful optical or radio telescopes on Earth. By locating the origin of the bursts (probably within our own galaxy), scientists hope to deduce what extra ordinary physical events produce these enormously high energy explosions. None of the theories proposed in the past few years satisfactorily accounts for the gamma ray bursts.

One popular theory suggests the existence of binary star systems involving a star like the sun and an extremely dense entity such as a black hole. Bursts occur when chunks of stellar material flowing from the star fall into the black hole. This event ignites thermonuclear explosions much like hydrogen bomb blasts and gives off high energy gamma rays which streak across the universe at the speed of light. The leading candidate for such a system is Cygnus X-1 in our galaxy.

Other theories propose comets colliding with dense neutron stars or gigantic outbursts from brilliant supernovae as causes of gamma ray bursts.

Pioneer Venus 1 was launched May 20,1978,from Cape Canaveral, Fla., and is due to arrive at Venus Dec. 4, 1978, where it will orbit around the planet.

Pioneer Venus 2, which will split into five atmosphere entry spacecraft eight million miles from Venus, will arrive on Dec. 9, 1978, five days after the orbiter.

Black Hole Theory Weakens

Black holes do not provide rapid transit links to other universes, according to recent mathematical research.

It appears that black holes in one universe are not intimately linked to white holes in another like two sides of a coin, as some theorists have proposed (see ASTRONOMY, November 1976). The theory that white holes exist like cosmic gushers at the centers of active galaxies and quasars, pouring matter into our universe from another, is apparently erroneous.

The error is understandable. Basic black hole theory states that the extreme curvature of space and time inside a black hole should connect our universe with another through what is termed a space-time bridge. This theoretical picture is idealized, and the real world is never that ideal. When extra effects are taken into account, the space-time bridges are broken.

For instance, many black holes are likely to have large masses of gas and other matter pouring into them. This iscertainly the case with the black hole believed to exist in the x-ray source Cygnus X-1, and it is the x-rays emitted by the hot gas plunging into the black hole that gives the object away.

But the matter falling into the black hole produces a gravitational effect of its own that destroys the neat symmetry of the black hole's internal geometry. Where does the matter falling into a black hole go? It stays in our own universe, and does not reappear elsewhere through a white hole.

This bridge-breaking effect of matter falling into a black hole has been realized for a few years, but it still left open the possibility that an isolated black hole could, in theory, provide a link into another universe — even if the very fact of jumping into the black hole destroyed that link.

But now, even this possibility has been shattered by mathematicians Nicholas Birrell and Paul Davies from Kings College (England). According to a recent article in **Nature**, Birrell and Davies found that any model of a black hole with a space bridge to another universe is an "unrealistic idealization".

Birrell and Davies looked at the small scale effects of space, known as quantum effects, operating inside the black hole. According to quantum theory, which describes these effects, empty space is not completely empty but full of energy, which increases in the presence of a gravitational field. In the intense gravitational fields within black holes, these quantum effects become very marked indeed. They have the effect of distorting the gravitational field inside the black hole, effectively twisting the neck of the space-time bridge and preventing any connection with another universe. This time, though, the break of the bridge is more fundamental than in the previous case, for these quantum effects operate on any black hole, whether or not it is sweeping up matter from the surrounding space.

Birrell and Davies concluded that models so far proposed in which the black hole links with another universe cannot exist in practice.

Booster May Save Skylab

A reusable booster system that can be remotely controlled may be used to push the Skylab orbiting space laboratory into a higher orbit and save NASA about $1 billion.

The Teleoperator Retrieval System (TRS) is a device — subject to Congressional approval — that would cost about $35 to $40 million. It would be used in October 1979 on the second Shuttle flight to either reboost Skylab to a higher orbit or deorbit it to a remote ocean area. Skylab is expected to burn up in the atmosphere sometime in late 1979 or early 1980 — hence, the fall 1979 launch date.

The schedule allows less than two years for development from its original inception in October 1977 to launch in October 1979. The low cost objective dictated maximum use of developed hardware. While the TRS and orbiter structures will be new designs, all other systems are designed almost completely with components that are either off-the-shelf hardware from other programs, or are under contract and will be tested before the TRS is used.

The TRS core vehicle will complement Shuttle orbiter capabilities for safe payload inspection and retrieval operations. Its compact, small size offers minimal cargo bay encroachment, as well as propellant savings for on-orbit maneuvering of payloads.

The core is equipped with a 24-nozzle attitude control system that provides six degrees of freedom in controlling the vehicle during rendezvous, docking and initial orientation. Its thrusters originally were designed for cold gas propulsion, but designers are now studying the possibility of using a lower cost hydrazine (hot gas) adaptation.

The strap-on propulsion kits contain a propulsion fuel tank and pressurant supply, and eight hydrazine rocket engines.

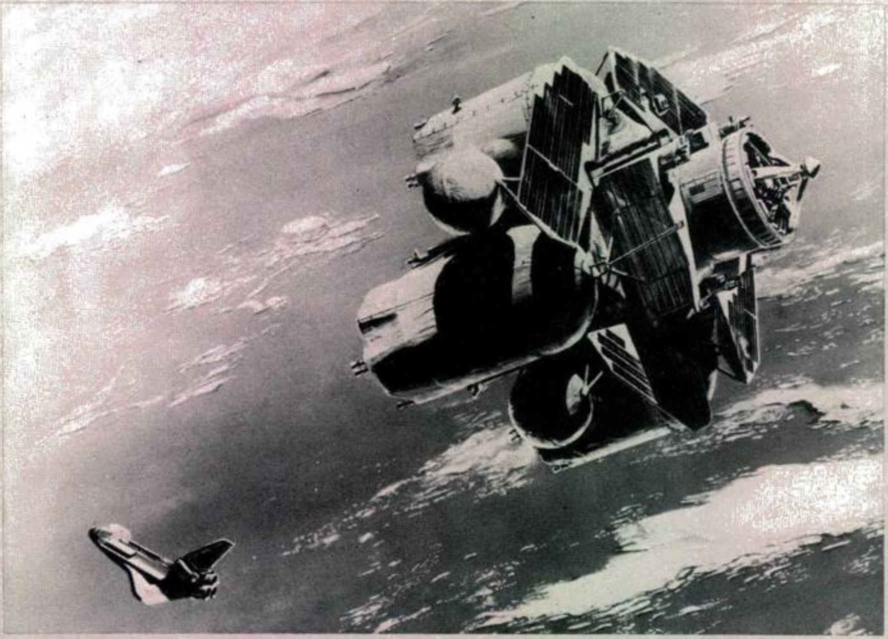
A Skylab reboost or deorbit mission will require four strap-on propulsion kits. One kit, 3 feet (0.9m) in diameter and 5 feet (1.5m) long, will be attached on each of the four long sides of TRS core. Each kit will carry 1,500 pounds (680kg) of hydrazine, and each of its eight rocket engines will have a minimum of 25 pounds of thrust, providing a total of at least 800 pounds of thrust for the Skylab re boost/deorbit mission. Many payload delivery missions will require only two strap-on kits.

Guidance and attitude control maneuvers can be controlled either through preprogramed instruction in the core communication and data management computer, or through manual control by a Shuttle crew member, using support equipment in the orbiter. Rendezvous maneuvering and docking with Skylab or any other objects in space would be accomplished remotely by the crew member, who could view the area around the docking adapter on a television monitor.

Following reboost or deorbit, the TRS will be separated from Skylab and placed in an orbital storage mode for retrieval on a subsequent Shuttle flight.

Typical of the growth applications are: payload retrieval at higher orbits than the Shuttle is designed to achieve; large structure assembly; emergency payload repairs, and retrieval of unstable objects or space debris.

A NASA spokesman said the agency was not yet sure what it would do with Skylab, but that two contracts had been granted to study possible uses. Various ideas, including refurbishing and using it as the core of a permanent space station or using it as a repowering and resupply station for long Shuttle flights, have been suggested. The decision to either reboost or deorbit is expected in early 1979.



NASA's Teleoperator Retrieval System (TRS) is being developed at Marshall Space Flight Center. The first mission for the system will either be to boost Skylab to a higher orbit or to control its reentry into Earth's atmosphere. The TRS is set for a Sept. 1, 1979 delivery date; hopefully it will be in time to save Skylab. Indications are that its orbit is degenerating at a faster rate than previously expected. NASA photograph.

Ariane *continued from page 63*

speaking of competition, an ESA official has referred openly to a "price war", with Ariane's $31 million ticket being artificially set below its $40 million cost. This will be slightly under the Shuttle's cost when Ariane's upper stages are included.

The first operational Ariane will launch an Exosat science satellite in early 1981, followed by a Marots B maritime communications satellite in mid-1981, the first operational European communications satellite, ECS-1, in late 1981, and a French Earth resources satellite (SPOT).

The fifth Ariane will be held in reserve, and a sixth may be built to launch a heavy direct broadcast television satellite (H-Sat) being studied by West Germany. Because Ariane is financed more by France than West Germany, the latter is giving equal consideration to Ariane and the Shuttle in designing the H-Sat.

Such European communications satellites are likely to be guaranteed fare for Ariane. Europe — France, in particular — has long been dependent on the United States for communications satellites and launches, and Ariane is a French-driven result of that.

Ariane will use French launch facilities at the equator on the South American coast.

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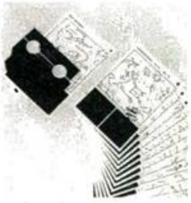

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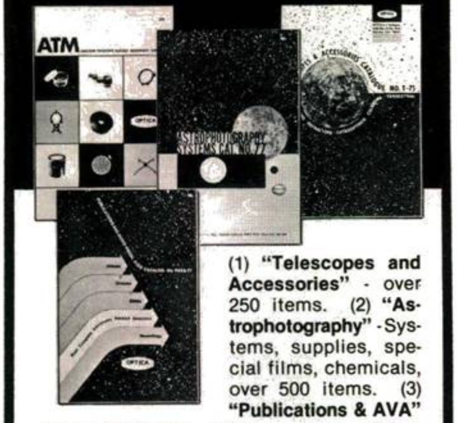

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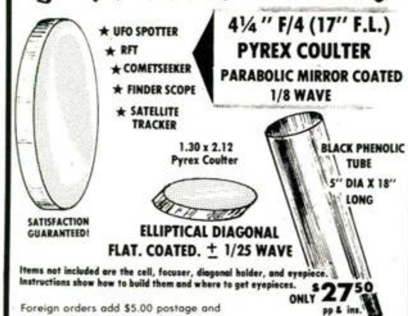

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In Focus *continued from page 16*

parabola of rotation as measured by a "wavelength of green light", the better the mirror. But manufacturers will not let one apply the rule in a straightforward manner.

For example, Meade states in its catalog that "...the best mirrors today are no better than the best mirrors of 20 years ago — it is only the *stated* accuracy that has 'improved'. The U.S. Bureau of Standards, with the finest optical test equipment in the world, will not certify any aspheric surface (including the parabolic surface) to an accuracy of better than 1/10 wavelength. They know that stated accuracies better than 1/10 wave are simply not meaningful."

Cave Optical write in its catalog, "It has been a company policy never to over-advertise our quality by means of fractional wavelengths. We prefer to be modest in our claims and advertisements." Yet, the Cave price list contains the claim that their diagonal flats are accurate from 1/12 to 1/16 wave or better. Since flats and primary mirrors are supposed to be of similar accuracy, this inspires the thought that Cave's primary mirrors are also this accurate.

Coulter routinely advertises its mirrors and flats as accurate to ±1/25 wave. Yet, it appears to be one of the more respected companies. This claim may be responsible for the following statement in the Cave price list: "Each (of our mirrors) is null-figured, and guaranteed to be noticeably superior to any other optics manufactured today. Do not be mislead [*sic*] by false wavelength claims or cheaper prices. In telescope optics, you get what you pay for." Coulter also advertises its mirrors at low prices.

Manufacturers may have their own private disputes with each other, but there appears to be a measurement problem that makes wavelength accuracy uncertain beyond a point. Beyond that point, the buyer has to try to find other criteria to rely on short of buying everybody's mirror and trying it himself.

What is the real story behind the wavelength controversy?

In the April 1978 issue of ASTRONOMY, there is a consideration that makes these questions even more important. In Robert E. Cox's article on reflectors, he states that the quality of a Newtonian telescope is affected by both the flat and the primary mirror such that if each element is accurate to 1/16 wave, the overall accuracy of the system is only half that — 1/8 wave. Thus, the standard suggested by Meade and the Bureau of Standards would not enable anyone to claim more than 1/5 wave for an entire optical system. This is only barely below the maximum error considered permissible for astronomical work, 1/4 wave.

Besides problems with wavelength figures, a buyer has to know some fundamental things about optics. 1) What, for example, is the relationship between focal ratio and resolving power? Resolving power is dependent on aperture; but it is not clear why RFT and other short focal length telescopes are, then, not considered good for high magnifications where the resolving power of the aperture could be fully used. Something is lost somewhere. 2) Why do you get a dimmer image with long focal lengths despite the light gathering power of a large aperture? The ultimate consideration is that the buyer has to have some way of determining what he needs.

3) How does "effective focal length" differ, if at all, from the properties of the focal length inherent in the primary mirror, and 4) can you get as much out of a device at the eyepiece which gives you so much more "e.f.l" as you would get out of a mirror of the same focal length, or do you lose something — resolution, perhaps?

STEVE KOKE
Rough and Ready, Calif.

Mr. Koke / Thank you for your perceptive questions. They demand a prompt answer, and we promise to follow up with an article in a future issue too.

The wavelength rating system is a quick, easy way to express the overall quality of an optical system, but it is, at best, only a rough guide. The distribution of the errors, the way in which they are measured, and the way the optics are used all influence telescope performance. Lord Rayleigh's 1/4 wave criterion specifies that rays of light coming to focus in an optical system within 1/4 of their wavelength will form a "sensibly perfect image". In reflecting optical systems, the light rays are set out of phase by 1/4 wave, by a 1/8 wave deviation in the mirror surface.

When companies claim mirror surface accuracy rather than wave front error, their claims look better. Also, the mirrors can be rated as ±1/8 wave, which means the same as 1/4 wave total error. If you combine two mirrors with the same type of deviation — each 1/8 wave at the mirror surface — you'll get a 1/4 wave error at each surface, and a 1/2 wave deviation as the light forms an image! If the errors happen to cancel in the particular instance — if one element has a +1/8 wave error and the other a -1/8 wave error — you might have an exact cancellation, and zero error optics! When combining optics of unknown errors, statistically you can expect a result equal to the square of the sum of the square roots of the surface accuracies. For two mirrors which are rated within 1/8 wave, the statistically expected error will be $(\sqrt{1/8} \times \sqrt{1/8})^2 = 1/5.6$ *wave — but depending on the actual errors could be anything from zero to 1/4 wave optics.*

The Bureau of Standards is quite sensible to refuse to certify (thus putting their reputation on the line) to better than 1/10 wave, though they can test to 1/100 wave. They don't know, for instance, that the glass won't warp over the years. In this sense, smaller wave ratings are not meaningful. But an entire assembled telescope with many surfaces in it can be tested to 1/10 accuracy and performs, all else being equal, marginally better than a telescope with known 1/4 wave errors. But under normal observing conditions, you may encounter 1/2 wave, 1 wave, even many waves of rapidly shifting air turbulence that largely obviate the need for precision optics — that is, optics much better than 1/4 wave.

From a practical standpoint, it's better to buy a telescope with a well-designed mounting than compare wave rating claims. If the scope shakes under moderately windy conditions, the advantages of good optics are lost on the mount. Consider, too, what you plan to do with the telescope. You don't need perfect optics if you'll habitually use the telescope at low power for finding nebulae or for prime focus astrophotography. But you'll want good optics, a good observing location, and a good mounting if you always want to push the telescope to its top powers on binaries or planetary astrophotography. Remember, too, that Rayleigh's limit provides "sensibly perfect" images at 1/4 wave accuracy.

By the way, the light wavelength usually referred to in testing is the 5460 A line of mercury vapor, which is close to the wavelength of peak visual sensitivity, 5550 A. Laser testing might tempt some manufacturers to quote in the helium-neon laser wavelength which is slightly longer than the green-mercury line.

In answer to your other questions:

1)There is no relationship between focal ratio and resolving power — resolving power depends on aperture only. RFTs and other short focus instruments are used with low powers because extremely short focus eyepieces necessary for high power with RFT optics are neither comfortable nor convenient to use. Longer focus mirrors permit longer focus eyepieces to give the same power. Long focus mirrors are easier to make and test; hence, the average f/10 mirror is better than the average f/4 mirror. The large secondary mirror in an RFT accounts for some light loss, and additional diffraction also leading to slightly degraded high power performance.

2) Although the image delivered to film is larger with a long focus mirror, if you use an eyepiece to give the same power as a short focus mirror of the same aperture, the image will have the exact same brightness. The image formed by a long focus mirror has the same amount of light in it as an image formed by a short focus mirror — but the light is spread out over a larger area. If you use the mirror for photography, you'll need a longer exposure (that is, the image is dimmer), but visually it's the power that counts.

3) Effective focal length differs little from focal length inherent in a primary mirror, at least in the center of the field. At the edges of the field, the image may be better or worse depending on the design and focal length of the compact system.

4) If you use a "well corrected" Barlow lens to increase the e.f.l. of your telescope, you'll lose a bit in ultimate performance, but gain convenience in using a comfortable eyepiece. An f/4 mirror and a 3x Barlow will give you the magnification of an f/12 mirror with a 12mm eyepiece that a 4mm eyepiece would give on the short focus mirror. The edges of the field might not be as sharp, however.

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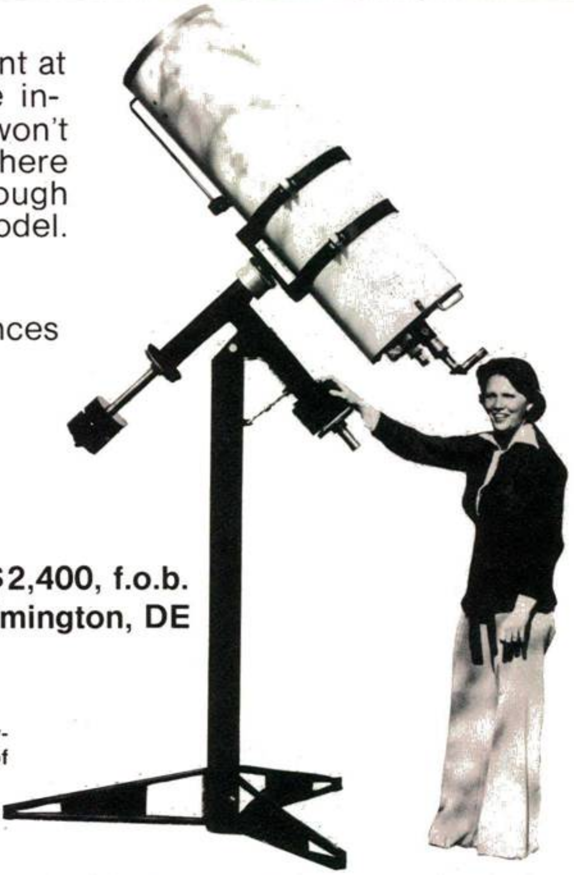

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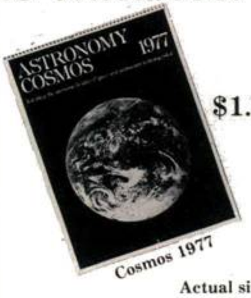

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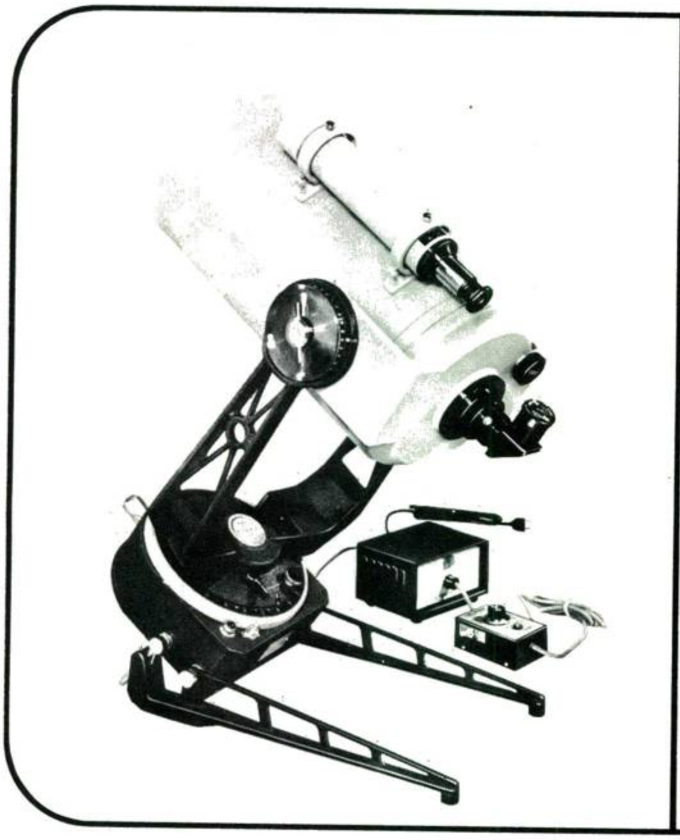

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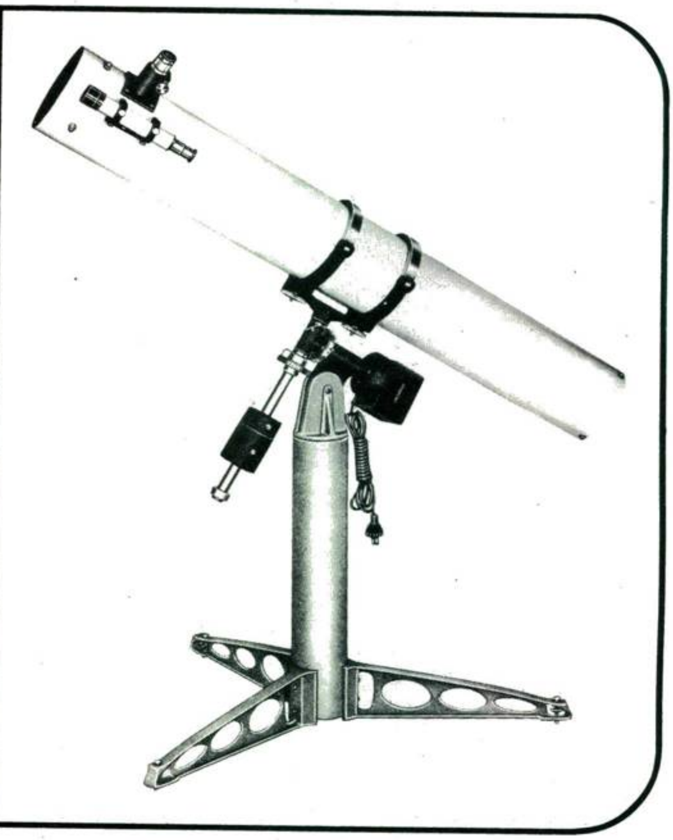

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STAR DOME

SEPTEMBER

by

John G. Harmon and James Mullaney

During the latter part of summer, we get a foreshadowing of the coming autumn in the form of Cygnus the swan flying south along the hazy band of the Milky Way. The Greeks first pictured this star pattern as a swan, although it has been seen as some sort of bird almost universally. The earliest concept — Urakhga, a giant bird like the roc in the adventures of Sinbad — was by the Sumerians. Arabs had a number of less fanciful views, all ornithological. To them, Cygnus was Al Dajajah the hen, Al Katat, a pigeonlike game bird, and Al Tair al Arduf, the flying eagle. The latter name was quite similar to their name for nearby Aquila, Al Nasr al Tair, also a flying eagle.

While the Greeks agreed these stars represented a swan, they did have a variety of views on who or what the swan itself represented. Some thought it was Orpheus, who was transformed into a swan and placed in the sky near Lyra (his harp). In another legend, Cygnus was the swan in whose form Zeus visited Leda, the wife of King Tyndarus of Sparta. (For more on the offspring of this somewhat unusual union, see Star Dome, February 1978.)

A variation gives Cycnus, which some authorities feel is the proper spelling of the name. Cycnus was a son of Neptune, and as such, couldn't be wounded by blows or weapons. He was finally overcome in battle by Achilles who smothered him, but before Achilles could rob Cycnus of his armor, he was transformed into a swan.

Finally, in the Metamorphoses, Ovid said that Cygnus (Cycnus) was the brother of Phaeton. Phaeton one day asked his father, the sun god Helios, if he could drive the sun's chariot across the sky. His request was granted, but the fiery chariot and team of four horses proved too much for him. The chariot of the sun passed too close to Earth and scorched the ground, leaving behind desert areas. To prevent further damage, Zeus killed Phaeton with a lightning bolt and Helios brought the sun chariot back on course. Phaeton's body fell into the river Eridanus. His sisters, the Heliades, wept for him by the side of the river until they were turned into poplar trees, and their tears to amber. When his brother Cygnus dove into the river to look for Phaeton's body, the gods took pity on him and changed him into a swan. It's said that when you see a swan swimming about with its head beneath the surface of the water, that it's Cygnus still looking for his brother's body.

The Mediterraneans were not alone in viewing this star group as a bird. American Indians saw these stars as a great thunderbird. To see it as such, you have to imagine that the thunderbird's tail is where we see the swan's head, and that Deneb, the constellation's brightest star, is at the base of the open beak.

This is backward from the traditional view, for in Arabic, Deneb means tail. The full name is Al Dhanab al Dajajah (the tail of the hen) — although it has also been known as Al Ridf, the hindmost.

Compared with th other members of the summer triangle — Vega in Lyra and Altair in Aquila — Deneb is the faintest of the three at magnitude +1.26. But this is true for their apparent brightnesses only, since Deneb is actually over 60,000 times brighter than our sun! Deneb appears dimmer in our sky because of its great distance; in fact at 1,600 light-years away, it's one of the most distant bright stars visible to the unaided eye.

Since distance plays an important part in determining how bright a star will appear in the sky, astronomers have devised a method of relating the actual brightness of a star, which is called absolute magnitude. The absolute magnitude is a measure of how bright the star would appear if it were placed at a standard distance from us of 10 parsecs or 32.6 light-years. At this distance, Deneb would brighten to a magnitude of -7 — or three magnitudes (16 times) brighter than the planet Venus. By the same token, if our sun were moved out to the same distance, it would dim to a magnitude of +5 and would barely be visible to the city dweller in the night sky.

At the other end of the constellation is a star named Albireo which marks the swan's head. This might at first seem to be a contraction of an Arabic name, Al Bireo — but no such name exists. The name apparently comes from a misunderstanding of a description of the constellation in a Latin translation of the **Almagest**, which contains the phrase "ut lilium ab ireo". By adding the letter "L", "abireo" became Albireo. The star did, however, have an Arabic name descriptive of its position: Al Minhar al Dajajah, or the hen's beak.

Cygnus is one of those constellations which has a common name as well as an official one. Because of its shape, it's known as the northern cross. The upright part of the cross is a line of stars from Alpha (Deneb) through Gamma, Eta and Omega, to Beta (Albireo). The arm of the cross is a line from Epsilon to Delta, which crosses the upright at Gamma. This corresponds to the part usually seen as the swan's wings.

Appropriately, the northern cross is most easily visualized at Christmas time when the constellation is standing nearly upright on the western horizon at sunset.

Close-Up

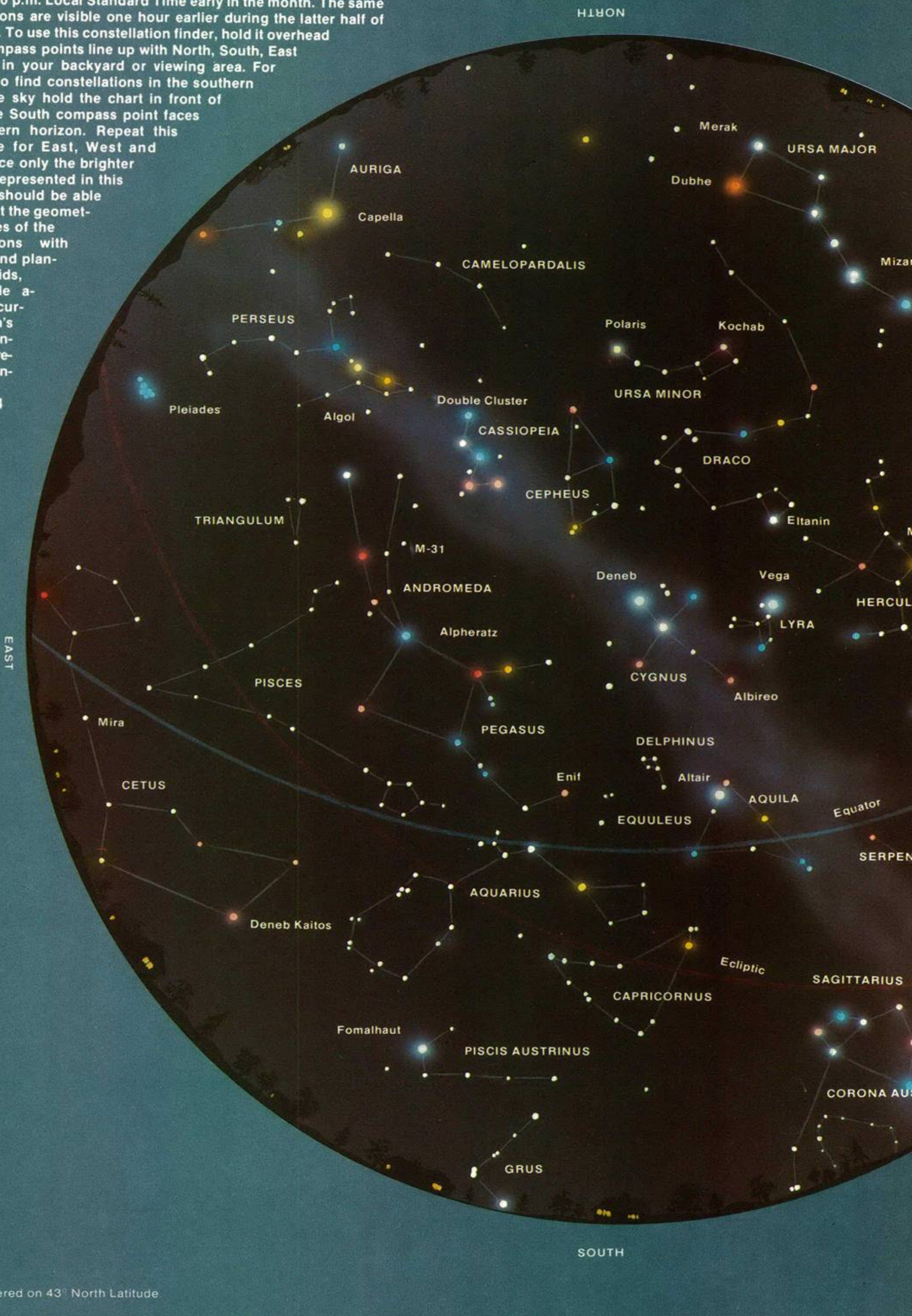
Cygnus Region

This month we explore what is probably the most thrilling portion of the entire Milky Way for northern hemisphere observers: the constellation Cygnus. This region is so rich and densely packed that you can see many apparent doubles, multiples, asterisms, star chains and clusters that appear in no star atlas or list!

Barns introduced his readers to this cosmic wonderland long ago as follows: "The graceful star-imagery of the Swan, with its six high-magnitude brilliants slanting a cross athwart the northern heavens, is the very ganglion of the Galaxy, making the search for reputed features rather difficult, since on every hand there is such a bewilderment of stellar riches."

Olcott pointed out that "to sweep over this region, even with an opera glass, is a delight." On clear moonless nights, binoculars and richest field

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 44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Merak
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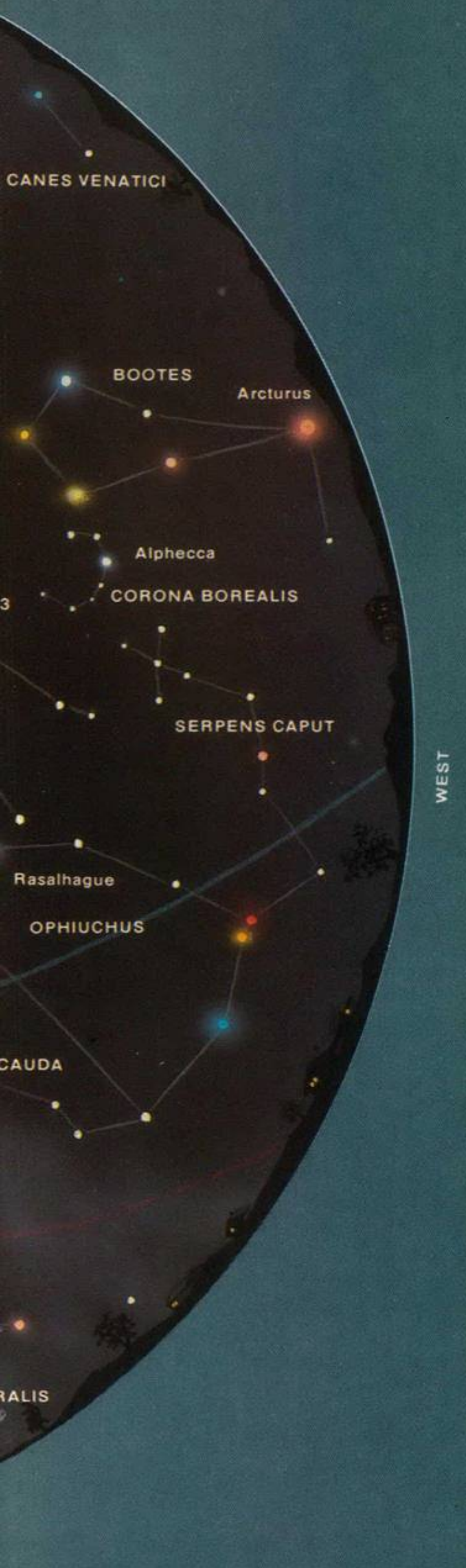
Dubhe
AURIGA
Capella
Mizar
CAMELOPARDALIS
PERSEUS
Polaris
Kochab
Pleiades
Algol
Double Cluster
URSA MINOR
CASSIOPEIA
DRACO
CEPHEUS
TRIANGULUM
Eltanin
M-31
ANDROMEDA
Deneb
Vega
HERCUL
LYRA
Alpheratz
EAST
PISCES
CYGNUS
Albireo
Mira
PEGASUS
DELPHINUS
CETUS
Enif
Altair
AQUILA
Equator
EQUULEUS
SERPEN
AQUARIUS
Deneb Kaitos
Ecliptic
SAGITTARIUS
CAPRICORNUS
Fomalhaut
PISCIS AUSTRINUS
CORONA AU
GRUS
SOUTH

Map Centered on 43° North Latitude



Map by Adolf Schaller

telescopes reveal such a display of celestial glory that the visual senses quickly become "saturated" and the mind numbed. As Webb put it, "Its low power fields are overpowering in magnificence."

Webb called Cygnus "a fine cruciform constellation" and offered a challenge that has gone unanswered for more than a century: "I had at one time projected a survey of the wonders of this region with a sweeping power; but a want of leisure, an unsuitable mounting, and the astonishing profusion of magnificence combined to render a task hopeless for me which, I trust, may be carried through by some future observer." Are you perhaps that future observer Webb referred to?

Muirden noted that the low power fields of Cygnus are "encrusted with stars" and that: "There seems to be no end to its pairs, triplets, and clusters. Fresh combinations continually delight the eye, and the background to these patterns is powdery with half-glimpsed points of light." Easily a year's worth of Close-Ups could be devoted to this month's region, and what follows must — of necessity — be only a limited sampling of the treasure awaiting you here.

Deneb

The brighest star in Cygnus is mighty Deneb — a blue-white supergiant of spectral type A2 marking the top of the well-known northern cross. Although at magnitude 1.3, it ranks as only the 19th brightest star in the heavens. Its true radiance and splendor is masked by its great distance of some 1,600 light-years, or more than 9,000 trillion miles! Among the most luminous supergiants known, this star outshines our sun by more than 60,000 times! At Deneb's distance, our sun would be near the limit of a six inch telescope. No wonder Barns called this solitary gem "a super sun"!

Chi (χ) Cygni

From a dazzling, steady blue-white star we move on to a restless, red pulsating sun that is an easy naked eye object at maximum light, but requires an eight inch aperture to be glimpsed at minimum. This is Chi Cygni, situated about midway between Beta (β) and Gamma (φ), some 2-1/2 degrees southwest of Eta (η).

A long-period variable star of the Mira Ceti type, Chi Cygni is generally regarded as the most striking and easily observed member of its class, with the exception of its prototype. Its maximum averages between fourth and fifth magnitudes (but has reached third on occasion). Minimum lies somewhere below 14th, and its period is 407 days. Its next maximum will occur this month on the 28th, making this an ideal time to become acquainted with the object. Nearby Eta Cygni, at magnitude 4.0, makes an excellent comparison star near peak brightness.

Chi's spectral class is given as late S by some authorities and as late M by others; in either case, it has a vivid red cast to it. Webb described it as "splendidly red, but suspected of losing color as it gains light". Can you confirm this from your own observations? In his **Celestial Handbook**, Robert Burnham noted: "Except when near minimum, Chi Cygni stands out vividly against (its) background like a glowing red beacon."

Beta Cygni

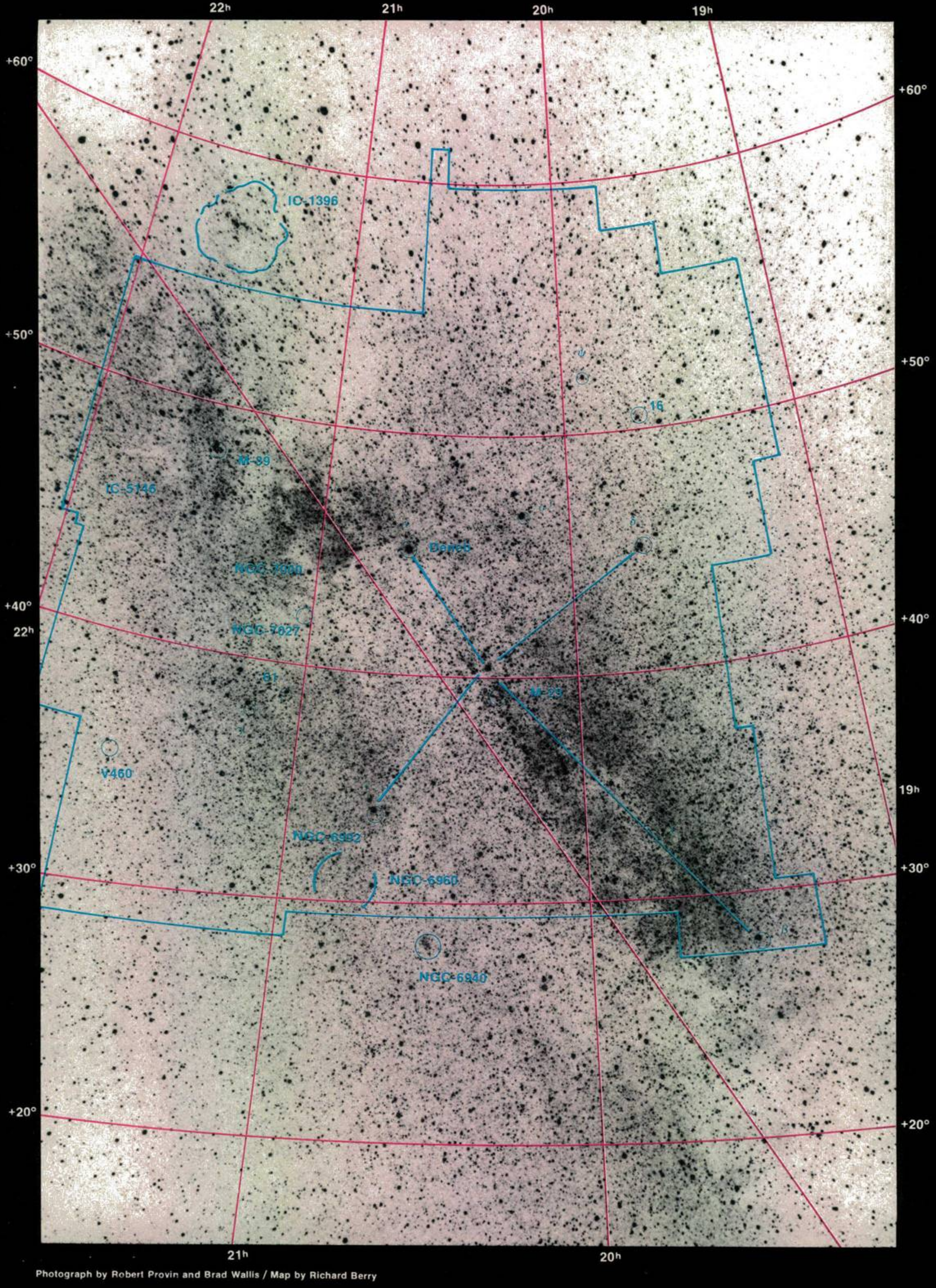
Turning our attention now from single suns to double and multiple ones, our next stop is Beta Cygni at the foot of the cross. Better known as Albireo, this object ranks as the finest double star in the northern sky for small telescopes. Our drawing with a four inch reflector at 60 power hints at its exquisite beauty.

Here we find a third magnitude orange star (type K3) and a fifth magnitude blue (type B8) companion 35 seconds of arc apart near position angle 55 degrees in a rich stellar setting. The tints are quite marked and best seen in three to six inch telescopes; the color diminishes as aperture increases here, as is often the case for bright pairs.

So many are the descriptions of Albireo that we can only offer a roundup of impressions here: "gold yellow, smalt blue"; "topaz and sapphire"; "yellow and blue — one of the finest in the heavens"; "gold and azure...the most lovely effect of color in the heavens"; "thrilling pair!"; "absolutely superb!"; "grand contrast"; "glorious pair; yellow and greenish"; "midyellow, intense blue — one of the showpieces of the sky", and "splendid fixed pair, superb color contrast".

As if we need say any more, a few additional commentaries may still be of interest. Brown called Albireo "wide spaced" and stated: "You are not a stargazer if you haven't seen this popular double." Pickering remarked: "If the components were closer, it would rank higher, since the colors are very marked." (He used an 11 inch refractor for his observations, supporting our earlier statement about larger apertures.) Webb remarked, "I have seen the colors beautifully by putting the stars out of focus" — always a useful technique with bright pairs. And finally, Smyth noted that the tints are actually different here — not the result of complimentary color contrast — as can be seen by hiding one component at a time outside the edge of the field, or better yet, behind an occulting bar in the eyepiece.

Albireo is a very long-period binary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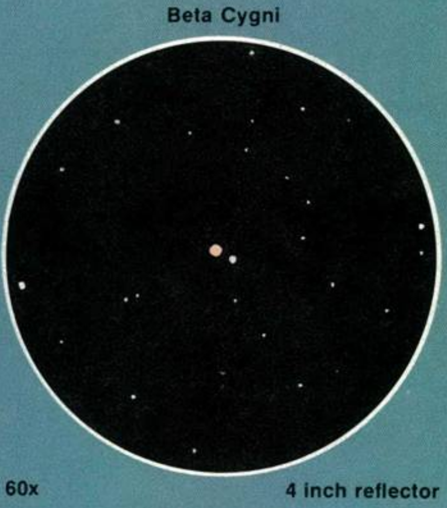
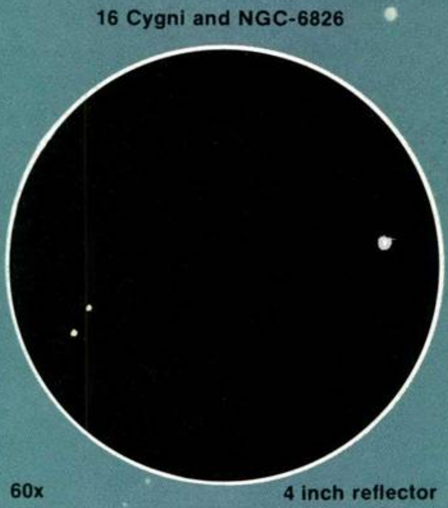
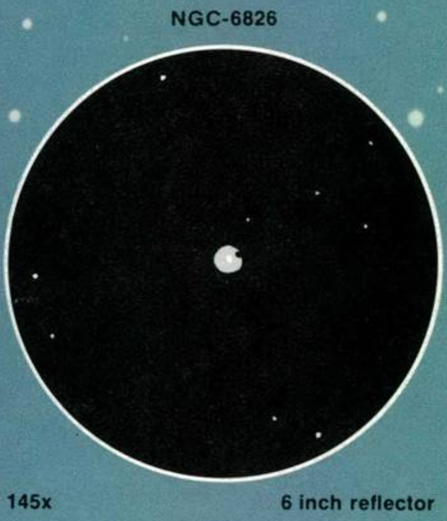
IC 1396
ψ
16
M 39
IC 5146
Deneb
δ
NGC 7000
NGC 7027
61
M 29
V460
NGC 6992
NGC 6960
NGC 6940
β

Photograph by Robert Provin and Brad Wallis / Map by Richard Berry system, and the primary displays a composite spectrum indicating the presence of a third star here. This lovely duo lies about 410 light-years from us, against the sparkling backdrop of the summer Milky Way.







Top left: Beta Cygni — best known as Albireo — is one of the prettiest and most striking color contrasted doubles in the sky. Even the smallest apertures show it well. Top right: The famous Blinking Planetary lies 3/4 degree from the golden duo of 16 Cygni. Bottom: Though you may spy the central star by adverted vision, looking directly at it causes it to vanish! Drawings by James Mullaney.

61 Cygni

Another noted double star in this region is 61 Cygni. A line from Deneb through Nu (ν) Cygni points to its place as the western member of a naked eye trio of stars. Even a two inch scope at 30 power shows this stunning pair of fifth and sixth magnitude orange K-type dwarf suns, an easy 28 seconds apart in position angle 120 degrees. Webb gave the following account: "Yelllow, deeper yellow. One of the most interesting objects in the sky."

In addition to its visual appeal, 61 Cygni is of interest on several other accounts. It was one of the very first stars to have its distance determined by trigonometric parallax (by Bessel in 1838) and is among our nearest stellar neighbors at just 11.2 light-years. It also has a large proper motion of better than five seconds of arc per year across the sky. Perturbations in this motion indicate the presence of at least one low mass unseen companion object apparently circling the brighter star. Among others, Belgium astronomer Jean Meeus believes "this companion can be called a planet, for its mass is only 0.008 that of the sun (eight times that of Jupiter), and its period is 4.8 years." The orbital period of the two stars we see about their common center of gravity is on the order of 700 years. They were closest in 1650 at 11 seconds, and will be at their widest of 34 seconds around the year 2,100.

Omicron^1 Cygni

Our next offering is a very wide but colorful triple star lying about four degrees west and one degree north of Deneb. This object consists of fourth magnitude Omicron^1 Cygni, together with fifth magnitude 30 Cygni 338 seconds away and a seventh magnitude star at 107 seconds. (Omicron^2 is located about one degree north of these three stars.) All three components can be seen in tripod mounted binoculars, and are a superb sight in a three or four inch scope at 30 to 45 power.

Although too wide in larger instruments for a pleasing effect, the colors displayed here are still quite striking. In order of brightness, this trio appears orange, white and blue to most observers, agreeing well with their respective spectral types of K2, A3 and B5. Barns noted this object as simply "wide" in his 10 inch reflector, but Webb left a more intriguing record: "Orange, two blue, 1838. Smyth found both the smaller stars cerulean blue when the larger one was concealed ....But I have noted (the fifth magnitude member) white, 3.7 inch (refractor), 1850; white or yellowish, 'with an eye of blue', 5.5 inch (refractor), 1865; 'pale yellow with a cast of blue, a strange but accurate description'; same colors 9.3 inch (reflector), 1867, 1869...."

Olcott mistakenly assigned this trio to the star Omicron^2, while Brown called the primary Omicron^2 and the fifth magnitude companion Omicron^1.

Selected Objects — Cygnus Region

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
*β(Beta)	★2	3.2,5.4	35″	19^h29^m	+27°52′
16	★2	6.3,6.4	39″	19^h40^m	+50°24′
*NGC-6826	PN	8.8	27″x24″	19^h43^m	+50°24′
δ (Delta)	★2	3.0,6.5	2″	19^h43^m	+45°00′
*χ (Chi)	RVS	3.3-14.2	407^d	19^h49^m	+32°47′
ϑ (Psi)	★2	4.9,7.4	3″	19^h54^m	+52°18′
*o^1 (Omicron One)	★3	4.0,5.0,7	338″,107″	20^h12^m	+46°35′
*M-29	OC	7	12′	20^h22^m	+38°21′
*Deneb	BWS	1.3	—	20^h40^m	+45°06′
*NGC-6960	DN	—	70′x6′	20^h44^m	+30°32′
*NGC-6992	DN	—	78′x8′	20^h54^m	+31°30′
*NGC-7000	DN	—	120′x100′	20^h57^m	+44°08′
NGC-7027	PN	10.4	18″x11″	21^h05^m	+42°02′
*61	★2	5.5,6.4	28″	21^h05^m	+38°30′
τ (Tau)	★2	3.9,6.3	0,9″	21^h13^m	+37°50′
*M-39	OC	5.2	30′	21^h30^m	+48°13′
V-460	RVS	6.1-7.0	—	21^h40^m	+35°17′
μ (Mu)	★2	5.7,6.1	1.8″	21^h42^m	+28°31′

*Detailed in Close-Up

★2 = Double Star
PN = Planetary Nebula
RVS = Red Variable Star
★3 = Triple Star
OC = Open Cluster
BWS = Blue-White Star
DN = Diffuse Nebula

It is wrongly plotted this way in both his **Mag 5 Star Atlas** and in the widely used **Norton's Star Atlas**; fortunately, Becvar's **Atlas of the Heavens** sets the record straight.

Omicron^1 Cygni itself is an eclipsing binary similar to famed Algol, but has the unusually long period of 3,803 days, or more than 10 years!

M-29

Two of Charles Messier's open star clusters lie in Cygnus, together with dozens of NGC ones that he some how overlooked. One of these is M-29, situated two degrees south and slightly east of Gamma Cygni, half lost in the rich stellar background. Visible in a finder as a misty patch, it's best picked up by sweeping with a low power eyepiece on the telescope itself.

M-29 shines near seventh magnitude and contains a dozen or so suns arranged in a trapezoid shape some 10 or 12 minutes in extent. Classified as loose and poor for its class, this cluster shows up well in a six inch scope at 50 power but is rather unimpressive to most viewers. Holyoke found: "It is quite difficult to pick out of its surroundings and the larger the telescope, the more difficult it becomes. Its beauty lies in the region it occupies which is unsurpassed anywhere in the sky." Many of the classic observers, including Webb and Barns, failed to even include this object in their works!

Deeply embedded in one of our galaxy's spiral arms at a distance of some 7,000 light-years from us, M-29 is heavily dimmed by intervening cosmic dust and gas, accounting for its subdued and neglected condition.

M-39

Much more rewarding for the visual observer is Messier's other find here, M-39. This is a wide, triangular shaped gathering of some two dozen stars in an area larger than the full moon. A fine sight in binoculars and RFTs, look for this fifth magnitude glow about 12 degrees northeast of Deneb, 3/4 of the way from that star and fourth magnitude Pi^2 Cygni.

Although classed as intermediate rich for an open cluster, most observers find it too coarse and large for a striking aspect in usual telescopic fields. Indeed, the **New General Catalogue** description in part reads "very large, very poor". Webb called it a "brilliant group and vicinity. Grand open cluster", and Barns, "grand open type". Smyth noted it as a "splashy field of stars". Being one of the brightest and easiest of Messier's clusters, it's well worth a look from our vantage point of nearly 1,000 light-years away.

NGC-7000

The Cygnus region abounds with bright and dark diffuse nebulosities, the great rift in the Milky Way being an obvious example of the latter. One of the most often pictured of the former is the North America nebula, NGC-7000. On a clear dark night, it can be glimpsed in 7 x 50 binoculars as a large (120 by 100 minutes), faint irregular glow three degrees due east of Deneb. Under exceptional conditions, it can even be seen by the unaided eye!

Discovered visually by William Herschel, NGC-7000 is perhaps at its best in a four inch RFT at 15 power. In such an instrument, the North America shape can be traced in almost its entirety on a good night away from city lights. However, as telescope size and power increase, its form dissolves away due to reduced field and poor contrast. Have you ever seen this famous object? Many observers have — as a brightening of the Milky Way in its position — without realizing it!

NGC-6960 and NGC-6992

Another noted nebulosity of the Cygnus region is that formed by NGC-6960 and NGC-6992 — one variously known as the Cirrus, Filamentary, Loop, Network or Veil nebula! To find it (them), follow a line from Deneb through Epsilon to 52 Cygni. This last star is enmeshed in one of the nebula's two main arcs like a jewel in some cosmic ring.

RFTs, standard telescopes and even binoculars have all been used to glimpse this faint and extensive multiple object. However, a very dark night, wide field of view, averted vision and good dark adaptation are all essential for success in detecting it. NGC-6960 and NGC-6992 were both picked up visually by Herschel in his 18.8 inch metal mirrored reflector. Webb described the former as a "nebulous ray extending north and south of 52 (Cygni)" and the latter as "a large nebulosity in a curve". Together, they form a roughly circular ring some 2-1/2 degrees in diameter believed to be the remains of an ancient supernova outburst.

Burnham found NGC-6992 visible in a six or eight inch telescope at low power, "looking like a miniature Milky Way in itself" and as "a faint curved arc like a ghostly white rainbow over one degree in length". He called NGC-6960 a "difficult and indistinct object in a six inch glass" and pointed out: "It is a curious fact...that the brightest portion of the Veil nebula, NGC-6992, may be seen faintly but unmistakably in 7 x 50 binoculars."

NGC-6826

We conclude our survey of the wonders of Cygnus with a stop at one of the most unusual and sensational objects in the entire heavens. This is NGC-6826, better known as the Blinking Planetary nebula. It lies about 3/4 degree east of the fine golden duo 16 Cygni (see table), pointed to by a line from Deneb through Omicron^2 Cygni. Both planetary and double star fit neatly within a one degree eyepiece field, as our drawing with a four inch reflector at 60 power shows.

Another of the finds of Sir William Herschel during his sweeps of the heavens, this object is also designated H^{IV}-73 or H 73^4 in some atlases. It appears as an eighth magnitude disk measuring 27 by 24 seconds of arc in size, at the center of which is an 11th magnitude star — the source of this nebula's eerie pale blue glow. Some sources rate this nucleus at least a magnitude brighter, which agrees better with the visual impression.

A three inch refractor at 45 power shows NGC-6826 as a nonstellar object and reveals a definite disk at 90 diameters. As telescopic aperture increases, both its visual appearance and the effect now to be described become ever more striking. Our drawing with a six inch reflector at 145 power clearly shows the bluish nebula and bright nucleus.

The name Blinking Planetary is derived from the fact that if you look directly at the central star, the nebula itself is completely invisible; if you then switch to averted vision, the star is suddenly drowned out by the bright blue nebulosity. Rapidly alternating between direct and averted vision produces a spectacular blinking on-and-off effect! Certain other planetaries (including NGC-7027 — see table) exhibit this unusual phenomenon but not to the degree that NGC-6826 does.

Curiously, none of the classic observers (including Herschel himself) mention this effect even though it is unmistakable in a four inch telescope, causing us to wonder if perhaps some change has occurred in this nebula's emission spectrum over the years. In any event, here is one of the few deep sky objects that "does something" at the eyepiece, making it a real hit with both seasoned observers and newcomers alike. If you haven't yet seen it, you're missing out on one of the sky's most fantastic sights!

Before ending your excursion through Cygnus and closing shop for the night, take a few moments to sweep over its magnificent star clouds with the telescope charged with a low power, wide field eyepiece. Here before you is the "Great White Way" of the heavenly City of the Stars. As Milton expressed it in his **Paradise Lost**:

> "A broad and ample road
>   whose dust is gold,
> And pavement stars, as
>   stars to thee appear
> Seen in the Galaxy, that
>   Milky Way...."

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Celestron 750mm Mirror Lens shot

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